MOTION AND FORCES: A VIEW OF STUDENTS' IDEAS IN RELATION TO PHYSICS TEACHING

NILZA MARIA VILHENA NUNES DA COSTA VASCONCELOS

Thesis submitted for degree of PhD at the Institute of Education,
University of London 1987

ABSTRACT

This study concerns students' ideas about the existence or otherwise of forces in several dynamical situations involving moving objects and objects at rest. It aims to contribute to a better understanding of students' ideas about dynamics. It differs from previous research (a) in covering a wider-range among students and larger variation in taught Physics background, (b) in attempting to tap less verbal forms of evidence and (c) in attempting to avoid 'scientifism' in terms of the way to approach students and in terms of interpreting results.

The empirical part of the study involved 338 students from seven different groups.

Data was collected from the above sample, using a questionnaire to which responses were simply graphic indications of the directions of expected forces, and, if possible, the giving of names to these forces, in eight situations presented diagrammatically. In addition, data was collected from a sub-sample, by means of computer games using a screen 'object' obeying Newtonian Mechanics, in a frictional and a non-frictional 'environment', under the control of the subject. Difficulties in interpreting the last kind of data led to the main study being focussed on the results of the questionnaire.

Some results from the computer games are however presented. They are mainly concerned with students' performance when playing in a frictional versus non-frictional 'environment'. Results suggest a better students' performance when playing in a frictional 'environment'.

Results obtained with the questionnaire concern:

(a) differences between situations in patterns of expected directions, among students of the same group and between groups. Generally the results suggest the existence of common patterns among the students of the same group and systematic differences between patterns of groups with an increase in exposure to physics teaching, namely the attribution of new force directions (e.g. vertical and downwards, opposite to motion), despite the persistence of primitive ideas (e.g. a force along the motion);

(b) names given to the different kinds of forces in various directions. Results include a difficulty found in naming forces which existed before teaching. They also give information about how scientific terms are assimilated.

Interpretations of the results, mainly taken from a theory of Common Sense Reasoning about motions proposed by Ogborn (1985), seem to give them a reasonable explanation. Although requiring further investigation, this gives some support to claim that students' intuitive ideas about dynamics should be regarded **(i)** as deriving from a rather general and coherent set of ideas, **(ii)** as less formalized in terms of the scientific world view and **(iii)** as having their origin mainly in actions on the world.

To the memory of

MY FATHER

and

PROF. J.E. LOUREIRO

AKNOWLEDGMENTS

Any human undertaking is the product of the efforts of a group of people who in some way contribute to its realization. A research project, a PhD thesis, are by no means an exception to this rule. The realization of this study was also made possible only by the contributions of numerous people, some who gave me practical help, others who kept me from feeling alone through the good and bad moments experienced over the years. They kept me going with constant encouragement and by believing in me even when I doubted myself. I include here particularly my friends everywhere, my family, colleagues and other members of the University of Aveiro. It is not possible to thank each individually, but I know they will recognize themselves from these words, and so I offer them my sincerest thanks.

Among these, however, there are some to whom I would like to give special mention for in some more direct or more constant way they have enable me to reach the end of this project.

Firstly I wish to sincerely thank my supervisor, **Jon Ogborn**, not only for all that he taught me but also for all his support and patience. To **Joan Bliss** also I owe a debt of thanks for the support she gave me, especially during a particularly critical period.

I am also deeply grateful to **Vasco** and **my Mother**, especially for all the support they gave my son Ricardo during my long absence.

Fundamental, also, was the contribution of **Doutor Óscar Gonçalves** during the final draft of the thesis. I thank him specially for having taught me to always write 'with a pencil and rubber'.

For the typing of this thesis I owe special thanks to **Mrs Rosa Regina** and for the diagrams, pictures and graphs to **Mr José Januário.**

Several institutions helped to make this study possible, namely the **Direcção Geral do Ensino Superior** which gave me a scholarship and paid my fees during my first three years in London, to the **University of Aveiro** which paid my last fees and to the **Calouste Gulbenkian Foundation** and **Instituto Nacional de Investigação Científica** who financed subsquent visits to England. Special thanks are due to the **Physics Department of the University of Aveiro** which released me from my teaching duties while I was preparing this work.

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CHAPTER 1

INTRODUCTION

In this opening Chapter there are three sections. The first, **Aims and Context of the Research,** describes the overall aims of the research and its context. The second, **Initial Orientations: Guidelines for the Research,** is a brief account of the preliminary steps of this work and of their influence on the formulation of the research. The last, **Outline of the Research,** is a brief description of the plan of the whole work.

1.1 - Aims and Context of the Research

The topic of this thesis is the investigation of students' ideas in dynamics, more specifically the existence or otherwise of forces in several situations involving moving objects and objects at rest, and how they vary with Physics teaching and age. This topic is not new in Science Education research, many studies having been conducted, over the past years, concerning the elicitation and description of students' conceptions about various scientific topics. From them, a vast amount of information is now available. However, while some researchers in the field are already engaged in developing strategies for school science teaching, which are aimed to promote a conceptual change in students' minds, others still claim that there is a certain lack of coherence in the seemingly quite disparate results. The last still seeking to achieve a deeper understanding of the object of enquiry, on the grounds that this will lead to more appropriate ways of taking into account students' conceptions within instruction. The present research shares this last point of view. Its prime aim being, then, to attempt to improve our knowledge about students' conceptions. In order to do so, the research is aimed, firstly, at the identification of some of the problematic issues which may have led to the state of the field and secondly, by taking them into consideration, to investigate further some of the existing results. Basically, the issues to be tackled concerned methodologies used and populations studied.

From the foregoing it is already clear that this research draws heavily on the existing literature on students' conceptions in science. The research is, however, also influenced by ideas on the nature of persons' everyday construction of knowledge and on how such activity is seen in comparison with the scientific endeavour [these ideas are presented in Chapter 3, sub-section 3.1.3]. The relevance of this issue arises from my belief in its central role for the understanding of the nature of the ideas students often express when answering to 'academic' situations [by 'academic' situations I mean to include, in general, all situations where students are asked about curriculum topics]. It also helps to question the scope of much of the existing researche, particularly in what concerns its focus mainly on students' ideas which derive from the school curriculum and the assumption it often seems to make [although not always explicit] that persons act and construct their daily life knowledge as scientists construct scientific knowledge.

1.2 - Initial Orientations: Guidelines for the Research

The formulation of the research was preceded by a stage oriented towards the understanding of existing researches in the field under study. The aim here is not to give a detailed analysis of them [this is done later, in Chapter 2] but to describe, briefly, the chronological path followed at the beginning of this work, and to present the main guidelines which emerged.

The work started by looking at Laurence Viennot's thesis [Viennot, 1977], on students' spontaneous ways of reasoning about elementary dynamics. Despite the interesting aspects found in this research, particularly because of the large number of students involved, the important results found and the interesting model proposed for students' reasoning in dynamics, I nevertheless felt somehow uneasy with respect to other aspects. These were, mainly, the rather formal and 'academic' nature of the questions used, the kind of analysis done [which was, fundamentally, based on the explanations students gave to Yes/No responses] and the nature of the results, which seemed to be formulated too much in terms of the scientific world view. To attempt to make these aspects clearer, a replication of some of Viennot's questions was done in a small scale study which involved eighteen P.G.C.E. Physics students [Vasconcelos, 1983]. The analysis done in this study was, however, somehow different from the one used by Viennot, particularly in that a separate analysis was carried out with respect to both kinds of data obtained [i.e. Yes/No replies and explanations]. Generally, the results found were rather similar to those identified by Viennot, for example, the high percentage of 'uncorrect' answers and the commonality of students' responses. The comparison of the analysis done with respect to Yes/No replies and explanations brought, however, some additional information, namely the higher percentage of students' Yes/No correct replies (67%, against 47% for the explanations), and the tendency for an increase in inconsistency when students' answered by giving explanations. This raised the following questions: why do students answer more 'correctly' and consistently by just giving an Yes/No reply than when they give an explanation? Could this mean that students are more sure, and 'right', about how things are than why they are as they are? The idea of planning a study which would avoid asking students for explanations had its roots here.

A further inspection of the explanations given by students, seemed to support my previous belief about the rather formal and academic nature of the study. Students often used expressions noticeably recognized as being school knowledge (e.g. mathematical expressions, like $M \frac{d^2x}{dt^2} = - Kx$). This led me to formulate the following question: to what extent did the formal and academic nature of the situations prompt students to formalize their beliefs in school like terms? More fundamental, could it be that the nature of this approach misled, or at least restricted, the identification of students' intuitive knowledge? The idea of approaching students, at a similar school level, with less formal situations to see the patterns which might emerge, become clearer.

Contact with other researches had also, at that time, influenced the plan of the study, particularly the work which had been conducted by the Personal Construct Knowledge Group (P.C.K.G.) at the University of Surrey. Firstly, the less formal nature of the situations used by the group, gave me some ideas for the design of a somewhat less formal and less school-like approach. However, despite their interesting results about students' ideas of word concepts (such as force, gravity), the group did not appear to me to offer a coherent and clear picture about how all these ideas were connected in students' minds. One of the reasons seen as having possibly contributed to this outcome was the strong emphasis given to students' verbal language. In other words, it seemed that this work was relying too much on the words students used to explain their beliefs. The work done by other researchers, especially diSessa and McCloskey, in which students' ideas were elicitated through their actions, as well as my belief that students' ideas about dynamics would come mainly from interactions with the physical world, motivated me to attempt a design which would rely less on verbal evidence and more on actions. The idea of using computer games on a large scale, for collecting data about students' actions, had its origin here. The use of this technique would also have the advantage of having a rather non-school like nature.

Another aspect of the existing research which highly influenced the plan of the study concerned the restricted range of students' age and Physics background involved in the studies done. For example, while some researchers investigated, mainly, students' conceptions of university Physics students (e.g. Clement, Viennot), others worked, mainly, at the secondary school level (e.g. the group from the University of Surrey). Nobody had, in fact, surveyed a wide range of students' age and Physics experience with the same method. If students' conceptions are fundamental and develop early, this becames essential, in particular, to find out what effect Physics teaching has. This was the other main guideline taken here.

In summary, the main guidelines derived from this preliminary stage were that of designing a study which would avoid approaching students with formal and academic situations, which would give preference to students' actions, and which would look at a wide range of students' age and Physics background with the same method.

1.3 – Outline of the Research

A remark should be made firstly about the original idea, expressed above, of using computer games, given that they did not in the end have more than a minor role in the main study. This was mainly due to difficulties found with the interpretation of the results obtained (a discussion of this issue is given in Chapter 3, section 3.3). The main body of data was, instead, obtained with the use of a questionnaire, designed and used simultaneously with the computer games, in the first field-work stage. The questionnaire was, however, designed taking into account the guidelines expressed above. Generally, the questionnaire consisted of asking students to choose directions of forces which they thought to exist, in several situations involving moving objects and objects at rest. In addition, students were also asked to give a name for the forces chosen. The questionnaire was administered to 338 students belonging to seven groups which varied from youngest students with no formal teaching in Dynamics up to Physics training teachers.

The plan of the thesis is as follows. After this introductory chapter, a fuller analysis of the literature is given [Chapter 2]. This analysis asks why it is still difficult to understand the area of research. Chapter 3 contains the formulation of the present research by presenting a theoretical perspective on the nature of children's knowledge, the research questions, and the discussion of the study made with computer games and its implications for the main research. Chapter 4 presents the design of the questionnaire and the sampling process. The analysis of the results obtained with the questionnaire is given in the next three chapters [5 - 7]. The interpretations of the results found and the main conclusions are brought together in Chapter 8.

CHAPTER 2

LITERATURE REVIEW

There are three sections in this Chapter. The first, **Introduction,** gives a general picture of the state of the field of research in students' conceptions in science, particularly the claim that there is still a certain difficulty in understanding its results. The second, **A Look at Some Researches in Dynamics,** contains a more detailed description and discussion of selected researches in dynamics and the last section, **Final Comments,** summarizes the problematic issues raised.

2.1 – Introduction

The claim that children construct their own conceptions about the physical world is not new and can be traced back to the early studies of Jean Piaget [e.g. Piaget, 1929]. However, it is only since the seventies that educational researchers have been engaged in investigating such conceptions and their implications for school learning. Since then, there has been a rapid expansion of this field of enquiry, on a world-wide basis, and in various topics of science. Table 2.I gives examples of some of the many studies done and topics investigated.

TOPIC AREA	RESEARCHES
Dynamics	Champagne, Klopfer, Solomon and Cahn (1980) Clement (1982) diSessa (1981a) Gilbert, Watts and Osborne (1982) Sjøberg and Lie (1981) Viennot (1979a)
Electricity	Osborne (1981) Shipstone (1984)
Heat	Brook, Briggs, Bell and Driver (1984) Clough and Driver (1985) Erickson (1979)
Kinematics	Crépault (1981) Saltiel (1978)
Light	Andersson and Kärrqvist (1983) Watts (1985)
Living	Brumby (1981)
Mole	Duncan and Johnstone (1973)

TABLE 2.1 - Examples of researches and topics investigated in the area of students' conceptions in Science

From the above and other studies there is now a rich collection of results supporting the claim that students have their own conceptions about scientific topics, even before they enter school. There is also a general consensus among researchers that these conceptions are **(a)** at least partially organized, **(b)** show some consistency across populations, **(c)** differ from school science, **(d)** are, sometimes, extremely resistant to change and **(e)** need to be taken into account if teaching is to be effective.

Despite the above, the claim that it is still difficult to make sense of this range of results has been put forward by some researchers, for example:

'[...] I feel at this point some urgency for clarification of and agreement about the meaning and style of this kind of research, if only to avoid being submerged and frustrated by too many un-understandable and unusable 'research results'.'

(Guidoni, 1985, pp 133)

In attempting to answer the above problem a more detailed analysis of some researches is given in the next section. The purpose is not to give an exhaustive review of the studies done but to select researches to illustrate and raise issues seen as being problematic. These concern, mainly, epistemological issues (e.g. theoretical assumptions made) and methodological issues (e.g. approaches used). Their relevance is that they are related to the two following fundamental questions: **(a)** what is the nature of the knowledge acquired through experience? and **(b)** what is involved in being able to claim that one has discovered something about what someone else thinks?

The researches selected are all in the area of Dynamics because this is the topic of the present study, and because this topic is that where most studies have been conducted (for an extensive review see, for example, McDermott, 1984). The problematic issues to be raised could however also be applied to other topics.

2.2 - A Look at Some Researches in Dynamics

2.2.1 Review of researches of the 'Personal Construct' groups concerning scientific word-concepts

This sub-section reviews researches from the 'Concepts in Science Project' (University of Surrey, England), the 'Learning in Science Project' (New Zealand Department of Education, New Zealand), and from the 'Personal Construction of Knowledge Group (P.C.K.G)' (also from the University of Surrey). The researches show many important similarities in respect of assumptions made and approaches used. The more recent work of the 'Children's Learning in Science Project' (University of Leeds, England) is similar in many ways.

2.2.1.1 Motivation, Assumptions, Aims and Theoretical Background of the researches

Most of these researches appear to have in common a problem-orientation rather than a theoretical orientation. They are, however, somewhat less empirical than other approaches [e.g. Viennot, 1977] in that the theoretical basis from which they work is made more explicit.

2.2.1.1.1 Starting points seen as more problem-oriented

One of the main motivations often referred to in these researches [e.g. Osborne and Gilbert, 1979, Osborne, 1980, Watts, 1982] concerns the problem expressed by many teachers of science that students do not understand basic ideas of science. One important reason seen by the researchers is that students' conceptual understandings of the words used in science often differ from those of the teacher. In this context, researchers talk about the 'gulf of understanding' between teacher and taught, and about the need to bridge the 'semantic gap' between the two [e.g. Watts, 1982]. In this vein, one purpose is to find out how students tend to use a particular word which is also used in science [e.g. force, energy], and to help teachers to make an appraisal of students' understandings of various concepts. This goal is justified by the principle that effective teaching can only take place when it is based upon what the learner already knows.

One underlying assumption is that youngsters do not arrive at science lessons with an empty mind but that they have already construed their own meanings for many of concepts [and their labels] to be taught. More generally, researchers often refer to students' previous knowledge as **children's science** [e.g. Osborne et al, 1983] - 'the views of the world and meanings for words that children tend to acquire before they are formally taught science' - or as **alternative frameworks** [e.g. Watts, 1983] - 'person's imaginative efforts to describe and explain their physical world'. Terms like misconceptions or pre-conceptions, which are used by others to designate the outcomes in this area, are avoided. This indicates the strong epistemological status given to students' previous knowledge in this kind of research.

2.2.1.1.2 Starting points derived from a theoretical basis

Many of these researches share, with varying degrees of commitment, a theoretical starting point derived from the psychology of George Kelly, namely his theory of personal construct and his metaphor of 'man-the--scientist'. Basically, the general ideas taken from Kelly are:

(a) that each person constructs a representational model of the world, the model being subject to change over time;

(b) constructions of reality are constantly tested out and modified to allow better predictions in the future;

(c) the concern is with **conscious** self-regulation by a person of his own constructions;

(d) following Kelly's metaphor of 'man-the-scientist', people are seen as essentially inquisitive and constructively scientific.

Taken together, these ideas assume that the processes through which scientists structure their knowledge are similar to the way that people deliberately construct their own world views (Watts and Pope, 1982). It is also assumed that people can construe their environment in an infinite number of different ways; for example, Kelly is quoted as saying that events are subject to 'as great a variety of constructions as our wits would enable as to contrive' (Watts, 1982). Thus the emphasis is on the **uniqueness** of each person's construction of the world.

A further important theoretical assumption concerns the view taken of what a concept is, of what it is to understand a concept and of what is the key measure of concept attainment. This issue relates to the choice of methodology for investigating students' understanding of individual concepts (see, for example, Osborne and Gilbert, 1979), the Interview-About-Instances.

In contrast with other schools (see, for example, Gilbert and Watts, 1983, for a review of the issue), these workers have taken what can be called an 'actional' view of a concept. A concept is generally defined (e.g. Watts and Pope, 1982) as 'all the knowledge possessed by an individual that underlies a term of reference for an area of experience'. From this point of view, there is little distinction between a concept and a theory. Concepts are seen as active, constructive and intentional, in that they are ways of organising our experiences through intentions towards things and expectations of things, this process being always open to re-conceptualization through new experiences. Moreover, concepts are seen as multi-dimensional and as heavily context-dependent.

Concept understanding is seen as resulting from the interaction of four possible components (see Gilbert and Osborne, 1980): (1) memory of instances associated with a term, (2) memory of a description of the concept, (3) memory of instances and non-instances (the word-concept becoming attached to the abstract concept of the class), (4) induction of a description of a concept. Figure 2.1 shows these components.

	Externally Classified	Internally Classified
Specific Instances	Instances 'Externally' Classified as Exemplars and Non-Exemplars of a Concept	Instances 'Internally' Classified as Exemplars and Non-Exemplars of a Concept
Descriptive Statements	Descriptive Statements of Concept Attributes Obtained from 'External' Sources	Descriptive Statements of Concept Attributes Obtained from 'Internal' Considerations

Fig. 2.1 - A simplified view of concept attainment (from Gibert and Osborne, 1980)

The general idea is that understanding a concept means to be able to generalize to all possible instances that might be presented and to be able to descriminate all possible non-instances. Thus, the key measure of concept attainment is 'the ability of an individual to properly categorize instances not previously encountered as instances or non-instances, of the particular concept' (Gilbert and Osborne, 1980).

This trend of research is, then, supported by a theoretical background which offers reasons why students construct their own conceptions and which charcterizes them in general terms. There are two limitations which I see in the kind of theory offered and in the way it is used.

Firstly, the theory is not intended to explain why the particular conceptions that do arise are of one kind rather than another. In other words, it does not offer a theory of the content of these conceptions. Secondly, the validity of the theory for this field of research is never questioned. These seem to me to be problematic because (a) there is not yet a general agreement in the field about the nature and construction of everyday knowledge, and (b) there are some arguments in the literature (e.g. Scheweder, 1977) which question the theoretical approach followed, particularly the close parallel drawn between the processes used to acquire knowledge by everyday thinkers and by scientists.

2.2.1.2 Empirical studies

This sub-section comments on the most relevant empirical studies carried out in the area of dynamics.

2.2.1.2.1 Focus of the studies

Generally, the focus of the studies concerns basic word-concepts used in science lessons, primarily the concept of force, gravity also being investigated, and to a lesser extent friction. Table 2.II shows the studies selected to describe this research.

SPECIFIC TOPIC	
FORCE :	Osborne and Gilbert (1980a), Watts and Zylbersztajn (1981), Watts (1983), Watts and Gilbert (undated, but published after 1983), Osborne and Freyberg (1985)
GRAVITY :	Stead and Osborne (1981b), Watts (1982), Watts and Gilbert (undated, but published after 1982)
FRICTION :	Stead and Osborne, (1981a)

TABLE 2.II - Examples of researches and specific topics, selected in this review

It follows that these studies concern only students' concepts which have the same names as physics concepts. Although understandable from a pragmatic point of view, it seems to me problematic that one might, in this way, be restricting the scope of students' knowledge which is studied. Why should students' everyday knowledge be formulated in the same terms as those of the physicist?

2.2.1.2.2 Methodologies

2.2.1.2.2.1 The Interview-About-Instances method

These researchers developed a specific method, namely, the Interview-About-Instances method (I.A.I.). Although this is not the only method used, its used is central because it was fundamentally based on the theoretical approach.

In outline, the I.A.I. method (see, for example, Osborne and Gilbert, 1979) consists of tape-recorded discussions with a pupil, using a series of picture-cards, concerned with the application of one word as a focus. Each picture-card depicts a line drawing of a situation which may or may not represent an example of the concept. As seen by Osborne and Gilbert (1979) the key problem in this method is how to select a necessary and sufficient set of cards which will effectively explore the dimensions and boundaries of the concept. To achieve this, it was necessary to consider: the theoretical structure of the concept, attributes of the concept, comments from experienced teachers on common difficulties, ideas from illustrations in textbooks. Figure 2.2 shows examples of some of the cards used by Watts (1983) for the concept of force.

IMAGE REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

[redacted]

Fig. 2.2 - Examples of cards used in the I.A.I. method, by Watts (1983) for the concept of force

Questions like, 'Do the situations represent examples of **your** concept of force?', 'Why do you say that there is a force here?', 'What would your example of force be?', were often used to prompt discussion.

One may describe the situations presented as relatively informal (by contrast with other examples, e.g. Viennot, 1979a). However the questions asked are still formulated in a school-like terms (e.g. by asking about force, gravity and by requiring always explanations from students). One may ask whether or not students would give answers in terms of those school-like terms when not prompted to do so. More fundamentally, one may doubt whether students conceptualize everyday like events around the same central concepts as those used in science.

2.2.1.2.2.2 The survey approach

Following up Interviews-About-Instances, views identified through the interviews were studied using survey techniques (e.g. Stead and Osborne, 1981a and b, Watts and Zylbersztajn, 1981). These mainly consisted of paper-and-pencil questionnaires in a multiple-choice-with-explanation format. In each question one possible response was always the 'scientifically correct' answer, whilst at least one of the others was inspired by an alternative framework previously identified. The situations presented often stem directly from the interviews. Figure 2.3 shows examples of questions used in two of these studies (Watts and Zylbersztajn, 1981 and Stead and Osborne, 1981b).

IMAGE REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

[redacted]

(a)

(b)

Fig. 2.3 - Examples of questions asked using survey techniques, about (a) the concept of force (Watts and Zylbersztajn, 1981), (b) the concept of gravity (Stead and Osborne, 1981b)

It may be noted that firstly, not all the ideas identified in the interviews were checked out in the questionnaires (see, for example, Stead and Osborne, 1981a or b). Further, there is not always agreement on the way of paraphrasing the alternative frameworks described in the two approaches (see, for example, Watts and Gilbert, undated but published after 1983). The surveys also often bring out alternative frameworks which were not identified in the I.A.I. method. Thus, overall, the surveys do not seem to constitute a systematic corroboration of the studies using the I.A.I. method.

2.2.1.2.3 Samples

It is important to consider the age-range, Physics background and size of the samples used (though the researchers do not always give full details). The general features of the samples are given in figure 2.4.

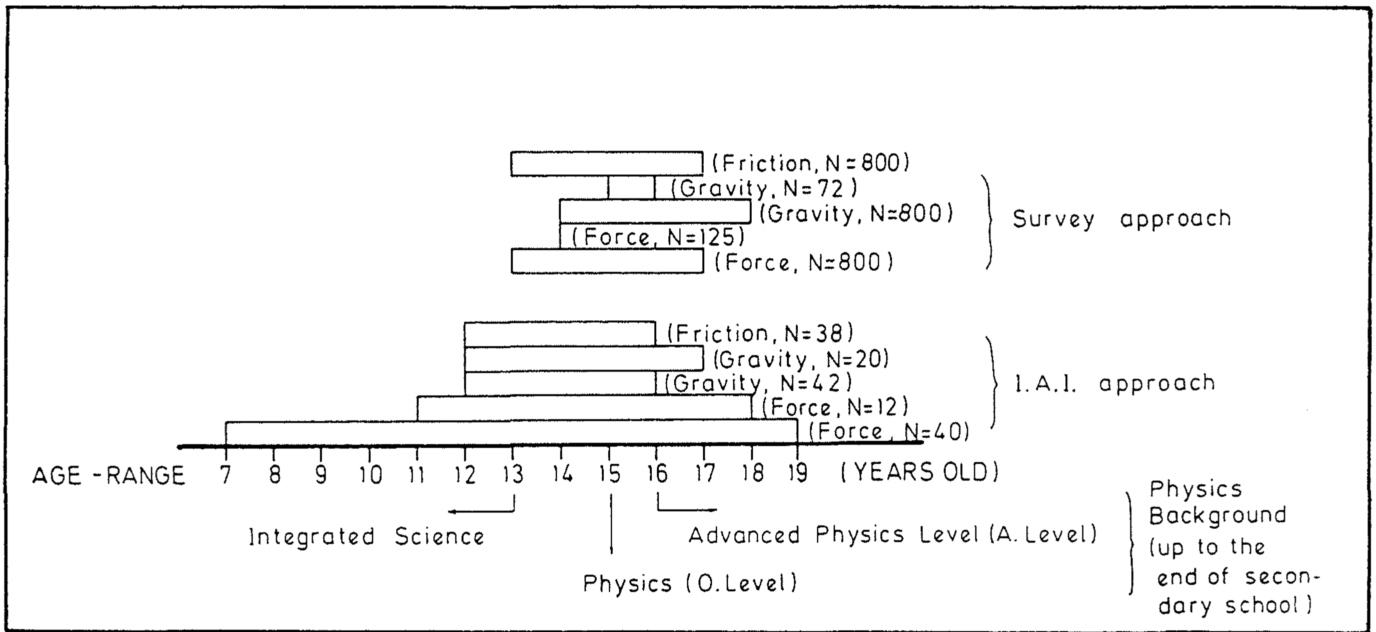


Fig. 2.4 - Characteristics of the samples of the studies reviewed

The general features of the samples can be summarized as follows:

(i) most studies covered a wide range of students' age, markedly between 12 and 17 years. The surveys involved a smaller range of ages and, particularly, involved older students;

(ii) the physics background of the samples mostly involved students with either no background in physics or with only some formal teaching in physics. All but one, involved only secondary school students. None of the studies involved university physics students;

(iii) the size of the samples varied markedly with the approach used, with many fewer students involved in the I.A.I. approach (between 12 to 42 students) than in the surveys (between 72 to 800 students).

The students involved come from two different countries, namely England and New Zealand, with some work in other countries (e.g. Portugal, Thomaz, 1983).

2.2.1.2.4 Aspects concerning the analysis of the data

With the I.A.I. approach the data to be analysed consisted of full transcripts of each individual interview. The analysis attempts to interpret students' understandings of a particular word-concept, through their use of this word. In most of these researches the aim of the analysis was to construct students' alternative frameworks, by which is meant 'a short summary description that attempts to capture both the explicit responses made and the construed intentions behind them' (Gilbert and Watts, 1983). Moreover, alternative frameworks may be seen as 'generalised non-individual descriptions' (Gilbert and Watts, 1983). So, the frameworks described come from no **one** student. Rather they were pieced together from the conceptions explicitly and implicitly used. Thus, the alternative frameworks identified do not tell what a particular student thinks of that concept.

2.2.1.2.5 Main results

2.2.1.2.5.1 Patterns of students' understandings in mechanics

General patterns of students' understandings with respect to their ideas in mechanics identified in early studies (Osborne and Gilbert, 1980a, Gilbert et al, 1982) include:

- **the use of everyday language** - a word is made sense of by placing an everyday interpretation on it. An example of this is given when a student, asked if there is a force when a man is pushing a car, answers 'yes, because he is forcing the car':

- **a self-centred and human-centred view point** - words and situations are considered in terms of human experiences and values. An example of this is when a student, asked if there is a force on a steadily moving bicycle with a man sitting still, answers 'no, because he is not pedalling or anything'.

The researchers do not make, at this stage, any statement about the comprehensiveness of the patterns identified, or their distribution amongst a population, or about the commitment of any student to only one pattern.

2.2.1.2.5.2 Alternative frameworks with respect to the topics investigated

2.2.1.2.5.2.1 Concept of force

The empirical studies of force have given rise to the identification of several distinct alternative frameworks. Watts (1983), for example, describes eight distinct alternative frameworks.

In order to understand better the rationale behind the description of such alternative frameworks, a discussion will be given of two of them.

(a) **A - Affective forces.** According to Watts, an appropriate description of this framework would be 'for force where objects are seen as inclined, or attempting, to produce action'. More specifically, this framework was paraphrased and illustrated by Watts, using extracts taken from transcripts as follows:

A_1 - Forces are obligations to complete an action against some resistance.

Ex: 'That [ball] **has** to do it ... if you hit the ball there it **has** to go up' [Golfball].

A_2 - The framework conveys an inner feeling of trying to accomplish some activity - an inner drive.

Ex: 'Well the tree is forcing itself to stay up ... it's being pulled by gravity but the tree's sort of **working** against the two' [Tree and wind].

A_3 - Forces are also intentional.

Ex: 'If you **do** something ... actually physically sort of dig something up ... **then** you would be causing forces ... like playing the piano'.

(b) D - **Designated forces.** This framework is paraphrased as follows: 'Forces are designated to those objects that are causing or will cause events to occur'. As before, this framework was illustrated:

D_1 - Humans are centres of force.

Ex: 'The force is coming from the man who whacks it' [Golfball].
'There's some force there from the teacher ... his power to tell the boy off ...' [Being told off].

D_2 - Forces are **inside** human bodies.

Ex: 'The force is **in him** ... striking the ball ... the movement of his arms' [Golfer].

D_3 - Forces in inanimate objects.

Ex: 'Yes, there is force in **the ball**, ... in the movement ... the whack of the thing' [Golfer].

However, in other studies involving the same researchers, paraphrased frameworks are: 'Forces are to do with living things', 'Constant motion requires a constant force', 'The amount of motion is proportional to the amount of force'. No clear statement is made about the overlaps, similarities and differences among the frameworks identified in different studies.

The prevalence of some of the frameworks identified was also investigated using survey techniques (e.g. Watts and Zylbersztajn, 1981, Osborne and Freyberg, 1985). Strong consensus was found for some views, particularly, concerning the association between force and motion.

Despite the interest of the wide catalogue of different meanings students may attribute to the concept of force, certain criticisms I would make are:

(i) in some cases, the alternative frameworks rely too much on the way students use a word. For example, the inclusion of the two examples given above for the first part of the **Designated Forces** frameworks (i.e. The Golfball and Being told off) suggests that the criteria used in the analysis were mainly the use of the **word** force and the context of the two situations rather than the understanding of the idea associated with the word force behind the answer. It is not clear that the result, for both situations, concerns the physical idea of force;

(ii) in some cases, the alternative frameworks seem to be too closely related to the context of the situation. In some cases a framework is even identified for a single situation.

2.2.1.2.5.2.2 Concept of gravity

The empirical studies of gravity have also given rise to identification of several distinct alternative frameworks. Watts (1982), for example, describes eight distinct frameworks: Gravity as being a force that requires a medium to act through (the air being the most popular candidate); Gravity as differing from weight, are just some of the ideas described.

In another study by Stead and Osborne (1981b) other views of gravity were identified, some of them similar, for example, the idea that gravity is the result of the presence of air pushing down and that gravity increases with height.

Most of the criticisms made before would apply also here. For example, one of the frameworks described by Watts (1982) is actually formulated in terms of only one kind of situation, namely a ball moving upwards in the air and then falling down. Furthermore, in the same study, one can find one student expressing ideas belonging to contradictory frameworks: 'Gravity is constant — moving objects try, and fail, to 'conteract' gravity' and 'Gravity begins to operate when objects start to fall down and continues until they are at rest on the ground'. This raises the question: if students' own ideas are so contradictory, how can one explain their persistence with age and formal teaching in physics?

The survey studies carried out showed the wide prevalence of certain views, such as, that gravity only exists on the earth and not on the moon.

2.2.1.2.5.2.3 Concept of friction

The concept of friction was only investigated in one study, by Stead and Osborne (1981a). This work identified several views held by students about the concept of friction, namely its close association with rubbing, particularly the rubbing of two solid surfaces, and with movement, wear, energy, and particularly heat energy. The prevalence of some of these views were investigated in a survey.

2.2.1.2.5.3 Main conclusions

The main conclusions seem to be:

(i) students do have their own meanings for words which are commonly used in physics lessons, and which they acquire even before they have any formal teaching in the subject. Moreover, these meanings are often at odds with orthodox physics;

(ii) for each word-concept, there is a proliferation of meanings, some of them seeming to be contradictory. Osborne, Bell and Gilbert (1983) state that 'children are not concerned with the need to have coherent and non-contradictory explanations for a variety of phenomena';

(iii) some of those meanings are widely held among students, although they are seen as individualized attempts to make sense of the world.

2.2.1.3 General Comments on the trend of research reviewed

The main problems I see with this line of research are:

(i) the focus of the investigations being only curriculum topics. This may miss essential aspects of students' everyday knowledge;

(ii) the emphasis on the consciousness of students' own constructions, which may have led researchers to base their studies on students' verbal knowledge and, particularly, on the explanatory framework they use for their responses;

(iii) the emphasis on the uniqueness of knowledge, seeing students' every-day conceptualizations as being individualized attempts to make sense of the world;

(iv) the diversity and nature of the outcomes found in the empirical studies, with the interpretation given to the results, being rather too closely related to the data and context;

(v) the lack of a general model which could account for the content of the conceptions identified.

2.2.2 Review of Viennot's research on students' spontaneous reasoning in dynamics

This sub-section reviews important research by Viennot (1977). It is important because it was one of the earliest studies conducted in the area, is a systematic large scale study of difficulties of dynamics and because it attempts to build an explanatory model.

2.2.2.1 Motivation, Assumptions, Aims and Theoretical Background

This work can be seen as being fundamentally, problem-oriented. As Viennot (1979a) writes:

> 'The work described here has its origins in practical teaching problems, and its ultimate aim is to contribute to an improvement of teaching'.
>
> (Viennot, 1979a, pp 205)

The immediate aim was 'to attempt to understand how students actually think about some specific situations, and to describe and formulate that thinking' (Viennot, 1979a).

One of its starting points is that students' difficulties should not be attributed solely to school learning but rather to students' own thinking. This is usually described by Viennot as students' 'spontaneous way of reasoning', a reasoning which is 'independent of teaching and which is taken to represent a common and self-consistent system which resists change'.

2.2.2.2 Empirical study

2.2.2.2.1 Focus of the study

The topic studied was elementary dynamics, that is, the relations between force, energy and motion. The topic chosen is, then, taken from the science curriculum.

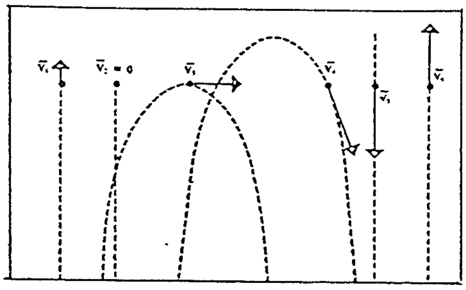
2.2.2.2.2 Methodology

The technique consisted of 1/2 to 1 hour long pencil-and-paper questionnaires administered to classes. The design of the questionnaire was preceded by an exploratory phase where ideas for items were collected from teaching experience and interviews.

According to Viennot (1979b), good items would be those which gave evidence about the intuitive aspects of students' reasoning. Thus, for example, the motions presented in the questions were not arbitrarily chosen, but were deliberately chosen to include motions in the opposite direction to the resultant force. The questions were intended to avoid, as far as possible, other difficulties, especially mathematical ones. Information about physical relations relevant to the problems was often explicitly given.

The type of questions asked are illustrated by the two problems shown in figure 2.5.

A juggler plays with six identical balls. At time t, the six balls are in the air at the same height, on trajectories shown in dashed line in the figure. Also shown are the velocity vectors of the balls at this instant.

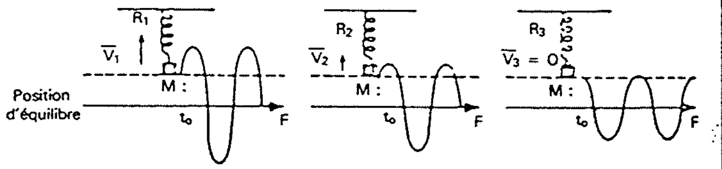


Are the forces acting on the balls at this instant the same or different ? Are some the same and the others different ? Justify your answer. (Neglect air resistance.) Are the potential energies of the six balls the same or different ?

(a)

Three identical vertical springs (R_1, R_2, R_3), each exert a force $F = -kx$ on a mass M that is fixed to the end of the spring. k is a constant and x is the elongation of the spring. M and k are the same for the three springs.

The three springs are fixed to the ceiling and oscillate without decay about their positions of equilibrium, with different amplitudes. At time t, when the end of R_3 reaches its maximum height (with velocity $V_3 = 0$), the end of R_1 and R_2 are at the same height but with different non-zero velocities V_1 and V_2.



For the three springs at this instant t, tell whether the total force acting on M is the same or different. Are the potential energies of the three mass the same or different ?

(b)

Fig. 2.5 - Type of questions in Viennot's research

The examples show how the questions are intended to ensure that students will not get answers 'wrong' because of lack of physical knowledge or because of the difficulty of the questions. Even so, these questions do seem to be rather formal or 'academic'. They are formulated in a way appropriate for students studying dynamics. One may ask whether presenting this kind of question may guide students to formulate their answers uniquely in school-like terms or concepts, thus limiting the extent to which the questions elicit students' intuitive knowledge.

2.2.2.2.3. Sample

The research involved about 1600 students, mainly French but also British and Belgian. The majority (2/3) were attending university degrees, mainly in science, though students studying science at the end of secondary school were also involved.

2.2.2.2.4 Aspects concerning the analysis of the data

Generally, the data collected consisted of Yes/No replies and written explanations. The analysis found the percentage of students giving correct/incorrect answers, together with inferences drawing on students' explanations about common kinds of reasoning. Notice that the data is mainly based on students' verbal knowledge.

In contrast to many other researchers, Viennot proposes a model to account for the findings of her research.

2.2.2.2.5 Main results and conclusions

The main results can be described as follows:

(i) **Commonality of students' responses** - The results found show a high frequency of similar responses, which were often in contradiction with the physicist's view. Moreover, the results also show that the types of answers varied little from one sample of students to another. This led Viennot to consider that students' difficulties in dynamics should be seen as resulting from a general and common spontaneous conceptual system acquired independently of teaching:

> 'It appears that spontaneous reasoning can be formalized in terms of its own 'laws'!'.
>
> (Viennot, 1979a, pp 205)

(ii) **Students' responses vary with the kind and nature of the situations presented** - Viennot found that students' responses varied with the kind of the situation presented. For example, when the motion is directly known as initial information and the motion is in the opposite direction to the resultant force, students often gave an incorrect answer by associating with the velocity a force which would explain the motion. To account for this result, Viennot proposes an intuitive 'law' of 'a pseudo-linear relation between force and velocity, $F \alpha v$'.

However, in other situations students correctly associated force with acceleration and not with velocity. These cases include situations where students were presented with an equation of motion and have to calculate the force, or when students were presented with a question such as 'If the same force acts on two identical masses, are the motions necessarily identical?'

(iii) **Model for spontaneous reasoning in dynamics** - Viennot's model assumes that students use different notions of force depending on the question asked. The model proposed is outlined in Table 2.III. Table 2.IV summarizes the nature and properties of two of the forces present in the model, namely the 'Force of interaction' (F_{act}) and the 'Supply of force' (F_s).

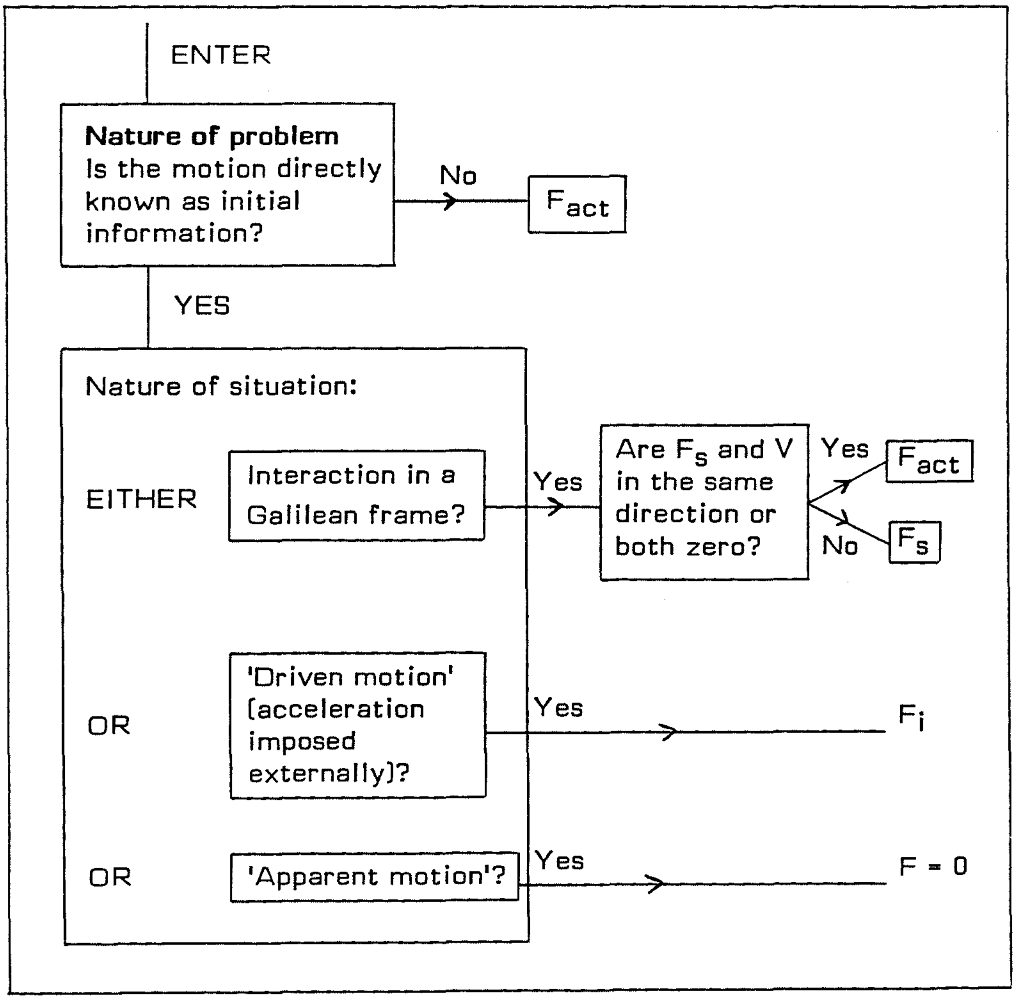


TABLE 2.III - Model for spontaneous reasoning in dynamics (from Viennot, 1979a)

	Symbol	Typical formulation	Physical nature	Localisation	Model used
Force of interaction	F_{act}	Force acting on the mass	Oriented (vectorial?)	Function of position	$F_{act} = m\ a$ a = acceleration
Supply of force	F_s	The force of the mass	Mixed scalar-vector: Force-energy confusions	A property of the whole motion: spatio-temporal delocalisation	$F_s = \alpha\ v$

TABLE 2.IV - Different notions of force in use among students (from Viennot, 1979a)

Comments on this model include the followings.

The model displays a certain 'scientifism'. That is, its formulation is in terms of rather formal and even mathematical relations. This appears to me to be a rather limited way of formulating students' own reasoning about everyday dynamics, biased towards a scientific perspective.

The model describes the empirical results rather than modelling the nature of spontaneous reasoning about everyday dynamics events. That is, its formulation is in terms of the link between the kind of situations presented and the kind of answers given.

(iv) **More general characteristics of students' spontaneous reasoning: widespread, tenacious and self-consistent** - Viennot proposes that the intuitive scheme of students' spontaneous way of reasoning in dynamics, is widespread and tenacious, and that it represents a worked-out effective and self-consistent system of thought. Its tenacity is, Viennot suggests, connected with its self-consistency. Viennot further supports this by tracing the same reasoning in a wide variety of sources, including newspaper articles, journals and even science textbooks. She notes, also, its similarities with a rather evolved scheme of historical thought, that of the impetus theory (Viennot, 1979b).

2.2.2.3 General comments on Viennot's research

The importance of this research derives, I think, from its systematic nature, in that it provides a good basis for recognizing the scope of students' difficulties in dynamics. Also, being one of the earliest studies done in the area, it may be credited as contributing importantly to abandoning the traditional perspective which considered students' difficulties as due only to misunderstandings of school learning.

Despite the above, the work is limited by the rather formal and school-like nature of the questions asked, by the population involved (mainly university students), and by the 'scientifism' of the model proposed for students' reasoning in dynamics.

Viennot's work, despite its value, is at best suggestive of how to build and test a model of thinking about motion in everyday life.

Similar issues, could be raised in connection with Clement's work (e.g. Clement, 1982), particularly the 'scientifism' of the approach to gathering and interpreting results, the limited scope of the study (e.g. topic taken from the curriculum, and the sample involving only universities physics students).

2.2.3 Review of diSessa's research on students' actions in controlling a computational environment

The work reviewed is that of diSessa at M.I.T.. The main point to be brought out in discussing it are the theoretical perspective taken, and the approach via students' actions rather than through propositional knowledge. The work of White (e.g. White, 1983), also from M.I.T., is similar in many ways.

2.2.3.1 Motivation, Assumptions, Aims and Theoretical Background

diSessa's work has a distinctively theoretical orientation, particularly the important role of prior, domain-specific knowledge (also designated Naive Knowledge or Intuition).

The general assumption underlying the work is that people hold an Intuitive Physics, learned from experience with the world, and generic [diSessa, 1986].

In an early paper diSessa [1978] argues about the 'mismatch between deductive systems and the character of human thought'. Even for the expert scientist, the formal structure of her/his field is seen as being only a small and sometimes superficial part of what s/he knows:

> '[...] it is a great mistake to identify knowing a field with knowing a formalism'.
>
> [diSessa, 1978, pp 253]

Great emphasis is given to 'knowledge-within-process', characterized by not being generally verbalized, by not being easily 'accessible' and by the non-conscious process of generating it, and by its vital importance to Intuition.

diSessa considers that persons reason by analogy and by induction, formulating heuristics and developing dispositions to act in certain ways in certain circumstances. Despite lack of rigor, they learn a great deal about the world and they learn it well in a **functional sense.** Thus, personal 'world models' are seen as secure in that they arise from procedures which work.

More specifically, diSessa [1981b and 1986] proposes that Intuitive Physics is a system of phenomenological primitives [p-prims] which are not often explicitly explained or justified but which serve as a foundation for all thinking or knowing. P-prims are collections of recognizable phenomena in terms of which persons see the world.

2.2.3.2 Empirical study

This sub-section considers one study by diSessa [1981a]. Given the limited scope of the study, particularly, the small sample, the discussion is brief.

The topic of the study was Newton's laws, including some aspects of vector algebra.

The technique used in the study was a computer game, in which the students had to control a graphical object, called a dynaturtle, which behaved according to Newton's laws. The dynaturtle could move on a CRT with commands typed at a keyboard, turning commands (i.e. RIGHT and LEFT, followed by a number telling how many degrees to turn) and a KICK command which gives the dynaturtle an impulse in the direction it is currently facing. The game (TARGET) has as goal to direct the dynaturtle to hit a target with a minimum speed. The initial configuration had the dynaturtle at rest aimed directly up the screen and the target positioned at bearing 45^0 from the dynaturtle (see figure 2.6).

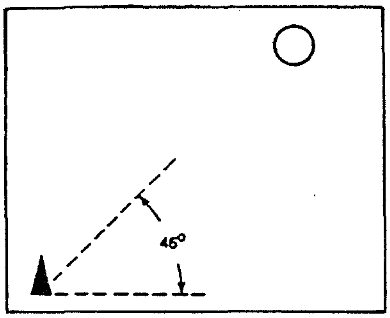


Fig. 2.6 - Initial configuration of TARGET game (from diSessa, 1981a)

The introduction to the dynaturtle given to students was a brief description of commands together with an illustration, applying a few kicks to a tennis ball on a table. Such a game, clearly, is not school-like in character, as compared with the questions asked in some other researches.

Most of the students involved had, previously, a considerable experience using the computer language, LOGO (i.e. eight weeks of roughly four hours per week).

Observations were made of students playing the games.

The sample consisted of eight sixth grade school children, aged 11 to 12 year old, who had no formal learning in dynamics, and one M.I.T. freshman student, who had already a year of highschool physics and nearly all the Newtonian mechanics in the freshman curriculum.

Basically, the data consisted of students' records, while playing the games, with notes on their comments and on the interventions made by the observer.

The analysis gives a description of the strategies used, which are abstracted and condensed into a list of students' theories and hypotheses about the dynaturtle. The end product was a 'learning paths chart', showing the essential features of development seen in the students. The alternative strategies discussed did not appear to be spontaneous but, instead, to be often a result of the observer's intervention.

The main results were:

(i) the youngest children showed a uniform common and robust 'Aristotelian' expectation that the dynaturtle should move in the direction it was last pushed. All initially used what diSessa calls 'Aristotelian corner strategy' (see figure 2.7).

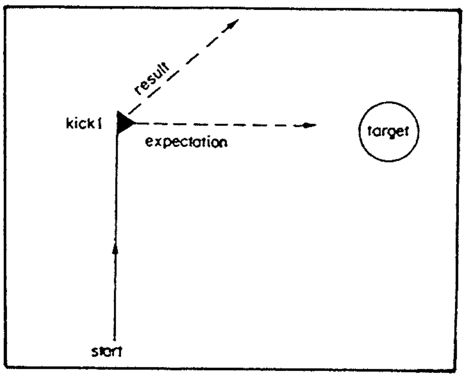


Fig. 2.7 - The Aristotelian corner strategy expectation and result (from diSessa, 1980)

Children were reluctant to abandon this strategy and showed surprised and consternation at its failure;

(ii) the M.I.T. freshman used much the same strategy, showing a marked lack of influence of formal learning in the subject. It was known that the student knew the formalism of Newtonian Physics, that the subject matter in the task was physics and was prompted, several times, to try to explain what was happening in terms of physics, without success.

diSessa explains these results firstly on grounds of the functionality of a non-Newtonian theory in everyday actions where impulse dominates momentum, and in terms of the nature of the physical world, in which the presence of friction supports Aristotle and refutes Newton. Secondly, diSessa argues that intuitive and classroom physics are disconnected because, for instance, when one teaches a new concept, say the 'concept of velocity', this is based on the logical components of its definition rather than by getting the students to interpret the naive phenomenology of motion as it relates to the 'new concept'.

2.2.3.3 General comments on the research reviewed

The main interesting and innovative aspects I see in this research are:

(i) the movement away from finding out what students know about a field by identifying what they say about a formalism. Particularly in the emphasis on students' actions and the non-school-like character of the technique used;

(ii) the attempt to systematically explore the evolution of knowledge;

(iii) the attempt to explain students' prior knowledge in terms of more 'natural' models of human reasoning.

The main problem I see is the validity of drawing definite conclusions from the study, given the small number of students involved and the interventions often made by the researcher during the experiment. Arguably, a large amount of theoretical speculation rests on a very small amount of experimental work.

A few other studies (e.g. McCloskey, 1983), in the field, were conducted using approaches with emphasis on actions.

2.3 - Final Comments

The previous section raised some issues which are seen as indicating a certain lack of cohesion, which still seems to characterize the field of research into students' conceptions in science, and possible problematic issues which contribute to the difficulty of understanding its results. They include:

(i) the non existance of a general agreement about the way to see students' conceptions. For example, whether they should be seen as individualized constructions, heavily context dependent, or as deriving from a rather unique model formalized in scientific terms;

(ii) the variety of approaches which have been used to investigate students' conceptions (e.g. rather formal and school-like questions administered to large samples of students mainly at the university physics level, interviews centred on less formal situations with individual students with no or little formal teaching in dynamics). Further, insufficient attention seems to have been given to the problem of how the different approaches may affect the results found;

(iii) despite of the variety of approaches, most of the researches seem to have some common threads which, as it was seen, may deserve further attention. They include, **(a)** focus on curriculum topics only, **(b)** the rather 'academic' nature of the situations presented to the students, **(c)** the emphasis on verbal or propositional knowledge and, particularly on students' explanatory framework, **(d)** the limited range of students age and physics background involved in each study, **(e)** interpretations given to the results in rather scientific terms;

(iv) the vast amount of information available about students' responses to particular situations but no general theory of how and why students come to have **those** ideas.

The need for a better understanding of the field of research under study and, particularly, of its results, is further supported by recent publications. An example being the group of four joint papers published in the European Journal of Science Education (i.e. by Guidoni, Ogborn, Viennot and by Hewson, 1985). Despite differencies in content and emphasis, all these papers attempt to suggest ideas which might lead to clarification in the field.

CHAPTER 3

FORMULATION OF THE PRESENT RESEARCH

There are three sections in this Chapter. The first, **Introduction**, discusses possibilities of research in the field of students' conceptions in science, and attempts to justify the kind of approach to be adopted on the basis of existing research and on some personal views about the nature of children's knowledge. The second, **General Features of the Present Research and Particular Research Questions**, specifies the aspects to be taken into account in the research, how they will be tackled and presents a list of the specific research questions addressed in the study. The last, **Minor Study: Implications for the Main Research**, describes a small scale study conducted in an attempt to assess students' ideas only through actions, and draws its implications for the main research.

3.1 - Introduction

The previous chapter argued for the need of a better understanding of the field of enquiry about students' conceptions in science. But what would it be to pursue research in this field? This issue is addressed, firstly by presenting two research questions drawn from the literature, which are relevant to guide further research, and by considering the different kinds of researches to which they may lead, giving reasons for adopting one kind. Secondly I present my personal view of some of the fundamental issues concerning the object of analysis of this field of enquiry, this constituting the theoretical perspective which contributed to the rationale behind the formulation of the present research.

3.1.1 General research questions

Two broad questions can be derived from the discussion of the literature. They are:

1. How can one see students' conceptions of the physical world if one wants to avoid seeing them just as a collection of quite disparate and often 'wrong' ideas about topics of curriculum science? Further, can they be seen as deriving from a more general, abstract and coherent theory of common sense knowledge about the physical world?

2. What kind of methodology may be used to elicit students' conceptions which would reduce the diversity in the outcomes which have emerged from previous research?

3.1.2 Two possible kinds of research to conduct

The first question may lead, if one believes (as I do) that such a theory exists, to an approach which would need to have a well-defined theory of the hypothesised structure, and which would test it in some sense. Only recently, however, have any such candidate theories been proposed (i.e. by Ogborn, 1985), and formulating one seemed to be an over-ambitious undertaking. So this was not the approach taken, though the present research will be, to some extent, influenced by such a theoretical perspective.

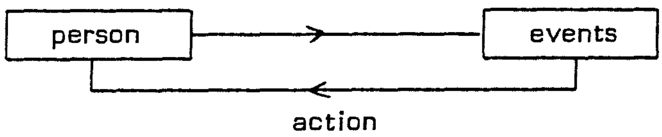
The second question leads to approaches with more modest aims, namely to investigate further some of the results found in other research as regards methodologies used. The present research is located here. More specifically, the research attempts to avoid some of the common methodological difficulties of other researches, which were seen in chpater 2 as being problematic.

3.1.3 Some personal views on the nature of children's knowledge

Following from the above, this research will operate at a level where it is not directly dependent on any theory of the content of pupils' conceptions. However, some views about the nature of children's knowledge do inform the work, even though much more thinking and research would be needed to test them. These will now be spelt out, by considering the four following issues:

(a) Origins of students' conceptions. Speculations about the origins of students' conceptions have been explored in the literature (for a review of this issue see, Driver and Erickson, 1983). Possible kinds of origins proposed are: kinaesthetic or sense experiences, language, and verbal and physical analogies. The view taken here is that for the area of dynamics, the most important origin is **persons' actions in the world** (e.g. when pushing, pulling, throwing, catching, lifting objects). It is assumed that the role of language is no more than secondary. This view questions, at least to some extent, the primary emphasis given to language by some researchers in the field. Some arguments which may account for the view taken, include: the nature of the domain of knowledge, the early experiences children have with motions and how well they can often predict motions even before they can talk, the non existence of noticeable differencies in students' conceptions in dynamics derived from studies done in countries with different languages;

(b) Everyday like activities and the construction of knowledge. One question one may ask is, if students' conceptions are highly influenced by their actions in the world, what are these interactions? Further, what kind of intellectual activity do they involve? Particularly, do they always require a self-reflective, intellectual activity? Its seems to me that the answer to this last question is: not always. Indeed, even admitting the complexity of the issue, a look into interactions between persons, in their daily activities, and moving bodies, might lead one to say that persons' behaviours are not all the time a 'thought behaviour'. Rather one may say that, often, persons interact with objects in a feedback loop as indicating in the following diagram:



The internalization of such action schemes would enable persons to solve most of their everyday dynamical situations. Furthermore, it would be from these that intuitive concepts would arise. Intuitive concepts would be, then, representations of schemes built from children's sensory experience. The view taken here, of thinking in terms of internalized action schemes, is basically Piagetian.

Two other features are attributed here to everyday activities and thinking, namely (1) the limited role given to consciousness in the construction of knowledge structures and (2) generally, the absence of the need to look for systematic explanations, particularly for things which always happen.

The first feature is still based on Piaget when he says that the child in her/his actions is only aware of the goal s/he wishes to attain and to the result of her/his actions but not to the structures and schemes that generate the strategies for reaching the goal. This view differs from the Kellian perspective which is concerned with the 'conscious self-regulation' (for further discussion of this issue see, Bliss, undated).

The second feature is supported, in particular, from arguments taken from a discussion by Nagel (1961) about the differences between Common Sense knowledge and Scientific Knowledge, when, for example, he writes:

> '(...) A marked feature of much information acquired in the course of ordinary experience is that, (...), it is seldom accompanied by any explanation of why the facts are as alleged (...)'
>
> (Nagel, 1961, pp 3)

Furthermore, persons in their everyday activities are not seen as seeking for explanations, or as recognizing factors, for things which are always present. Two possible examples being gravity and friction which, for their very presence, would be taken for granted.

The two aspects discussed above would question some researchers in the field when they claim the elicitation of students' conceptions by prompting answers and, particularly, explanations about scientific concepts like gravity and friction.

(c) Some hypotheses about the content of persons' everyday knowledge about dynamics. Based on the above views, an early attempt was made (Vasconcelos, 1983) to construct some of the ideas persons may hold about everyday dynamics. They include:

(1) – unsupported objects fall (gravity taken for granted)

(2) – objects in movement stop after a while if nothing is making them move (friction taken for granted)

(3) - objects go in the direction they are pushed, on plane surfaces

It may be interesting to notice the similiraties which appear to exist between the ideas mentioned and some of the p-prims defined by diSessa (1981b).

Moreover, the view adopted here is that ideas like those mentioned above are highly structured, constituting a general, abstract and coherent view that persons hold about the dynamical aspects of the world. Possible evidence supporting this view is taken from two general results of previous researches, namely (1) the consistency which seem to characterize some of students' conceptions, despite the diversity of methodologies used to elicitate them and (2) the strong resistance that such conceptions present to change.

(d) Common Sense Knowledge and Scientific Knowledge. Following from the points discussed above one may start seeing how and why students' own conceptions may differ from those of curriculum science. Actually, some arguments exist in the literature which point out some marked differences between Common Sense Knowledge and Scientific Knowledge (e.g. Castro, 1982, Nagel, 1961). Although researchers in the field under study do not seem to have paid much attention to such differences, and particularly to what Common Sense is, there are some exceptions (e.g. Noce and Vicentini-Missoni, 1982, Ruggiero et al, 1985) who have pointed out the importance of considering this aspect. My personal view goes also in this direction. Despite the complexity and difficulty of these questions, particularly because as Noce and Vicentini-Missoni (1982) wrote '(...) Common Sense has no history (...)' I believe that, by considering it, one may start to have a better understanding of, for example, why students' ideas are so stable (see, Castro, 1982 and Nagel, 1961).

3.2 - General Features of the Present Research and Particular Research Questions

The previous section pointed out that the formulation of the present research comes mainly from an analysis of existing studies, though it will be, to some extent, also influenced by the theoretical perspective outlined.

The analysis made in Chapter 2 pointed out that many existing researches are too special in scope and that this may have contributed to a certain diversity of the results found. Thus, the present study will attempt to extend their scope and, particularly, to avoid some features identified before as problematic. The specific aspects to be considered are:

- the tendency to use 'scientific' and 'formal' situations
- the tendency to focus on propositional knowledge, particularly on explanations
- the restricted range of students' age and Physics background

It was decided to design a study which would investigate a wide range of students' age and physics background, by including students with no formal teaching in dynamics up to university physics students, with a uniform methodology. This methodology would try to use less 'academic' and formal situations, particularly by avoiding focussing the study on curriculum topics like gravity and friction, and try to make less reliance on propositional knowledge, particularly by avoiding asking for verbal explanations.

The particular research questions which the study to be conducted would attempt to answer, include the following:

[1] Is diversity, in students' responses, reduced if one approaches students with less formal and verbal situations? In other words, can one, in this way, find a more general and coherent picture of students' ideas about dynamics?
In particular,

[1.1] Are students' responses, of a given age and physics background, better seen as derived from general common patterns rather than from individualized answers?

[1.2] Are students' responses then still to be seen as heavily context dependent? In other words, are students' ideas better seen as a collection of answers to particular situations or, rather, are they better seen as more general and less contextualized?

[1.3] Do students spontaneously formulate their answers about dynamical situations, in terms of say, gravity and friction, if not prompted to do so? Alternatively, do they simply not refer to these word-concepts, so that one might say that although students have some meanings for such words (as they are in use in ordinary speech), these concepts do not belong to students' primitive schemes concerning dynamics?

(2) How do students' answers differ with age and physics background, when approached with a uniform methodology?
In particular,

(2.1) How do students' answers differ with teaching?

(2.2) How do students' answers differ with age, i.e., if students have a similar physics background but different ages, do they answer differently?

A preliminary attempt to operationalize a research plan which would satisfy the aims discussed so far was done in a small-scale minor study. Broadly speaking, this study attempted to infer students' ideas **only** through their actions, while playing computer games. No 'scientific words' were used to introduce the task to the students, neither were interventions made by the researcher while students played the games. This idea was tried out on a small scale. Being a rather unusual approach, it is not surprising that it raised more problems than it solved. In the end, this very distinctive line of approach was not taken further, and a different rather more conventional main study (originally conducted in parallel with the minor study) was developed instead. The small scale study is, however, worth reporting as it has several implications for the design and analysis of the main study.

3.3 – Minor Study: Implications for the Main Research

3.3.1 Description of the study

Generally, the aim of this experiment was to assess students' understanding of dynamics, through their actions while playing computer games. Also, and given that the games were played in two different modes, namely with 'friction' and 'without friction', the aim was also to see to what extent students' behaviours changed in these two cases. The main assumption was that students would have to use their ideas about motion in order to understand and play the games and that the researcher might be able to infer such ideas, without asking students to verbalize them.

The task consisted of several computer games in which basically, the students had to control a spot, moving on the screen, according to Newtons' laws. For controlling it, the students had to apply discrete kicks in a desired direction. The direction was indicated by a plotted arrow, which the user could rotate in eight distinct directions in order to point it in the direction of the recquired kick. All commands are given key presses. Key K delivers a kick and three other keys (i.e. J, L and R) could be used to rotate the arrow. Alternatively, the student could do nothing, in which case the spot would move by itself. All the games could be run in two modes, namely in a 'pure' Newtonian Universe with no friction (zFr) and with friction (Fr). One of the games, SHOOT, had the spot initially moving horizontally on the upper part of the screen and the student had to land it on a small central square. The student would fail the game if the spot hit the 'walls' of the screen. Other games include: TAG, involving an attacker who tries to catch an escapee (either the computer or the student), MAZE, in which the student had to manoeuvre the spot into the centre of a maze. The games were played on a ZX Spectrum (48 K).

About fifty Portuguese students were involved, ranging from students without any teaching in dynamics up to first year university physics students who had already studied dynamics at high school and at the university.

Each student played several versions of the games, individually with the researcher during about one hour and half. At the beginning, the researcher introduced the game, its goal and the way to play it, and no further interventions were made. The same procedure was followed with respect to the other games students played. No reference was made to the subject matter of the task being physics.

The data consisted of full records of the way students' played the games which were obtained from a printer connected with the Spectrum, and on some notes taken from students' comments while playing.

3.3.2 Analysis of the results

3.3.2.1 Students' behaviours in playing games in a frictional and non-frictional 'environment'

Figure 3.1 shows the percentage of students who succeeded in playing the SHOOT game with and without friction, for each group of students. Group A corresponds to students without any formal teaching in dynamics, groups B and C to secondary school students with little and some formal teaching, respectively, and group D to university physics students. Similar results were found for the other games.

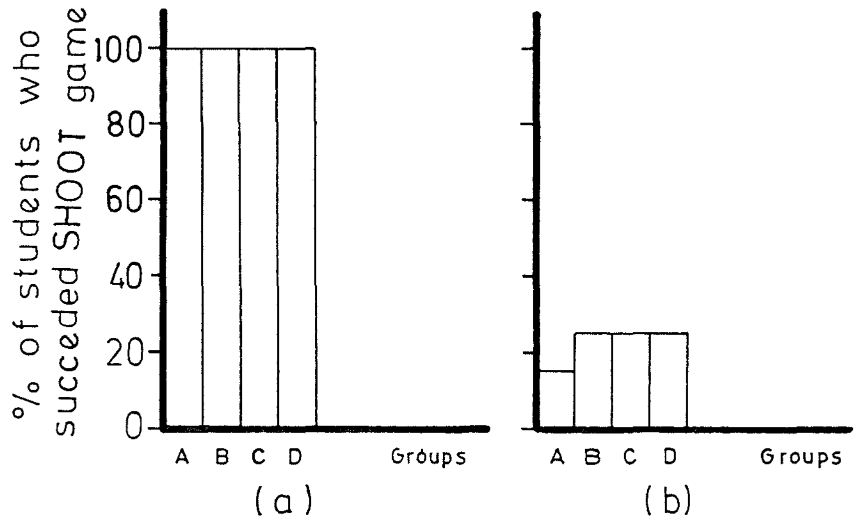


Fig. 3.1 - Percentage of students, of each group, who succeed SHOOT game [a] with friction and [b] without friction

As the results clearly indicate, students were much more successful in playing the game with friction than without friction. Even with an increase in teaching, only a minority succeed without friction. This suggests that the rules students used, while playing, worked much better in a frictional environment. This may also suggest that students' ideas are, at least to some extent, accurate in what concerns the characteristics of the physical world, despite the 'wrong' ideas students may hold about curriculum topics. However, students' ideas do not seem to work in a 'Newtonian' world, even after some years of formal teaching.

It may be also interesting to mention that students often expressed surprise and consternation towards the results of their actions while playing the games without friction. This seems to suggest how students' expectations and predictions about moving objects are at odds with 'Newtonian' objects.

3.3.2.2 Attempt to infer students' ideas about dynamics only through their actions

Several attempts were made to classify and interpret students' actions in terms of the ideas about motion which could have guided them. However, many difficulties were found in all these attempts. The following examples illustrate some of these difficulties, for the SHOOT game. They concern two common kinds of students' actions, namely kicking along the path of the motion and kicking to change the direction of the motion.

(a) Kick along the path

Figure 3.2 shows a student's record where arrows were drawn to indicate kicks the student gave in the direction of the previous motion of the spot, when it moves horizontally. (Other kicks given are not shown here).

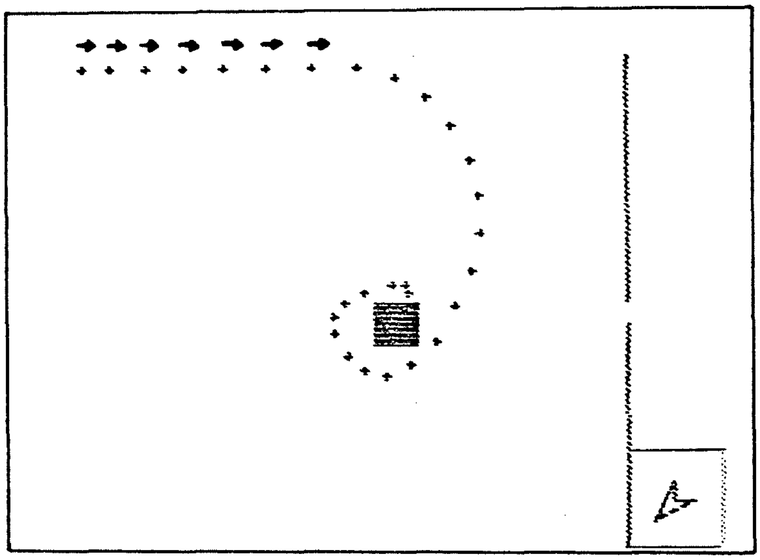


Fig. 3.2 - Example of a student's record, for the SHOOT game, with arrows representing kicks given along the path

It appears to me that several different interpretations could be given to this particular action, namely that (i) the student thought that a kick was needed to keep the motion going, this being, most probably, a manifestation of the 'force is required to maintain motion' idea, (ii) the student was only kicking in order for the spot to go faster so s/he was probably thinking in terms of 'more force, more speed' or (iii) even both.

(b) Kick to change direction

Figures 3.3 (a) and (b) show two different but common situations where a kick, represented by the arrow, is given to change direction. In both cases, the student's intention seems to be 'to kick in the desired direction, that is, towards the target'. However, and because **the speed is low,** the initial velocity of the spot does not have a big effect on the change of the direction of the motion. Therefore, one can not say, with certainty, whether the student was just believing that 'an object goes in the direction it is last pushed (no matter the initial velocity)' or if s/he was doing so because the speed was low.

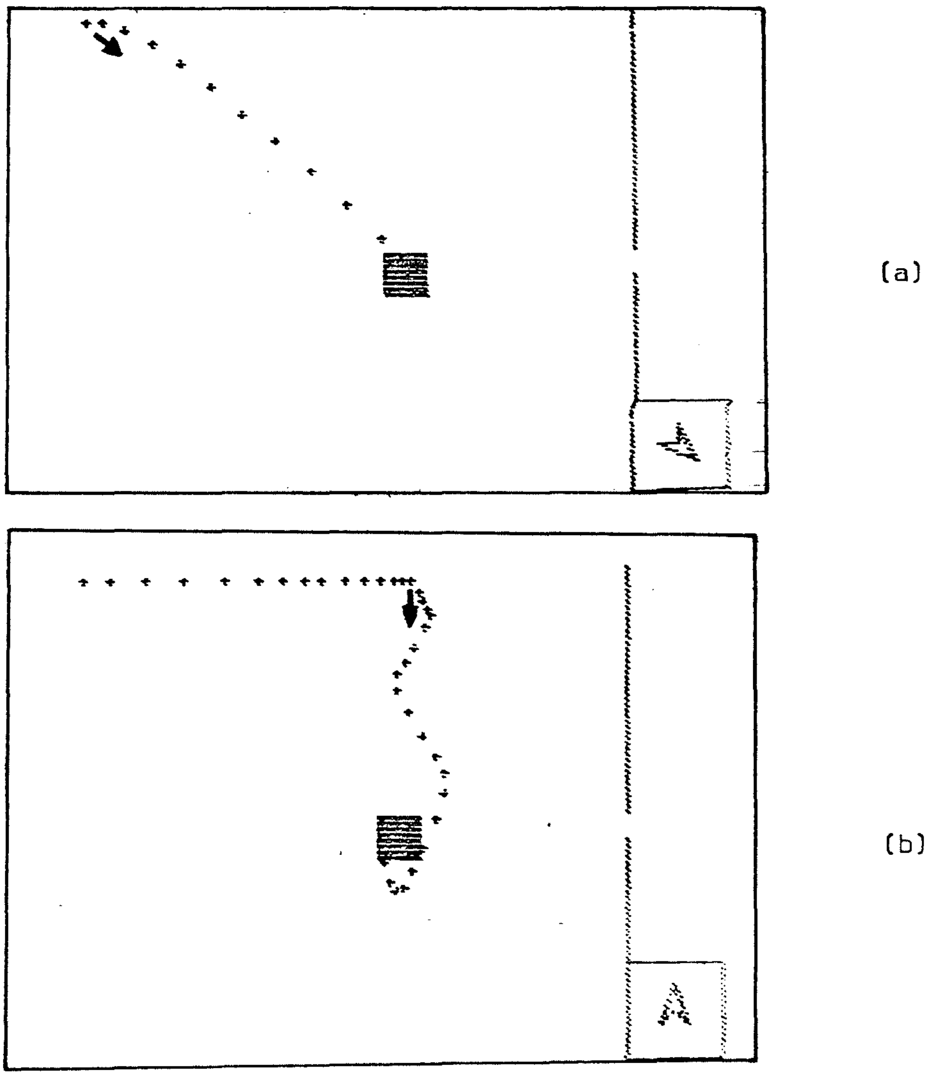


Fig. 3.3 - Examples of students' records, for the SHOOT game, with an arrow representing a kick to change direction

One last example is given, where one can not even decide whether the action represents a kick along the path, here to reduce speed, or a kick to change the direction, namely towards the target (see Figure 3.4). One of the reasons for considering the second case is that some of the students who made such a kick, showed consternation towards the effect of her/his action by saying, for example, 'the spot didn't obey ... it didn't go up'. However, insufficient evidence is available with such kind of data to make any conclusive statement.

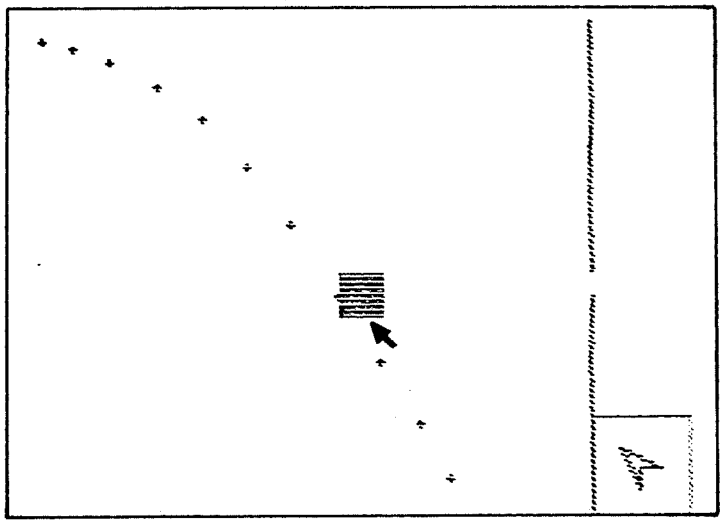


Fig. 3.4 - Example of a student's record, for the SHOOT game, with a student's action represented by an arrow

In contrast with the above examples, there are some situations where students' actions appear to have a clearer interpretation. An example is shown in Figure 3.5, where the kick drawn seems to suggest that the student was believing that 'an object would move in the direction it is last pushed' (so neglecting initial velocity).

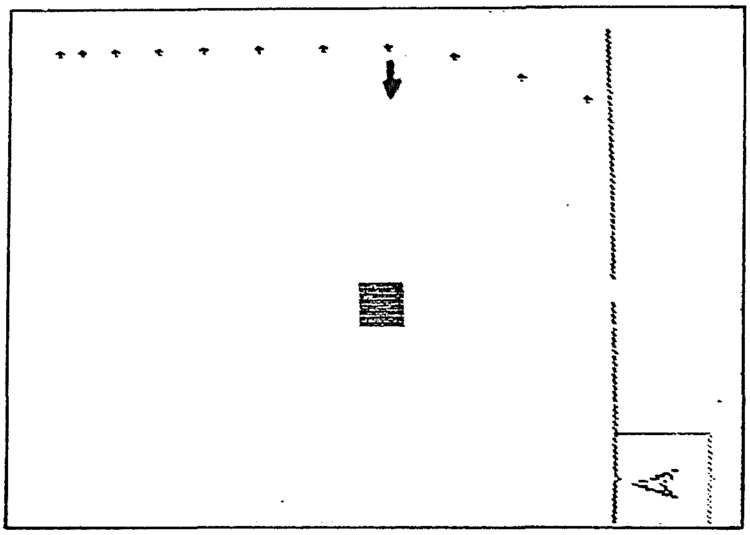


Fig. 3.5 - Example of a student's record, for the SHOOT game, the arrow indicating a kick given

However, such cases correspond mainly to situations where the **speed is high.** Given that, in these conditions, the possibility of students' actions becoming just reactions may increase considerably, the validity of the analysis may be questioned.

3.3.3 Final conclusions

Although it seemed very attractive to assess students' ideas about motions through their actions only, the analysis of the data presented difficulties and problems of interpretation. Actually, previous researchers working with students' actions, as diSessa, get, often, students' ideas through verbal communication. One could, also, have tried to develop further the study described above by, for example, asking students why they played the way they did. However interesting it could be, one would follow in a situation one wanted to avoid, that is, to base the analysis on verbal data and, particularly, on students' explanations. Therefore, it was decided to leave out from the main research the computer games and to pursue the research with a questionnaire centred on pictures and which tried to avoid, in particular, scientific words and justifications. This will be described in detail in the next Chapter.

CHAPTER 4

DESIGN OF THE SURVEY AND ITS ADMINISTRATION

The purpose of this Chapter is to describe the methodology used in the main study, which design stems from the aspects referred to in the previous chapter. The first section, **Design of the Questionnaire**, gives the reasons for the use of a questionnaire, discusses its design and describes the questionnaire construction. The second, **Sample**, discusses the sampling process and describes the different groups of students involved. The final section, **Administration**, describes the field-work stage.

4.1 – Design of the Questionnaire

4.1.1 Introduction

The main reasons for conducting a survey using a questionnaire, as opposed to other methods, were (a) the purpose of the research in covering a large sample, and (b) the difficulties foreseen if, say, interviews were used, in avoiding propositional data and in designing an interview schedule based on more natural terms than the scientific ones.

According to the general formulation of the present research (Chapter 3), the questionnaire should satisfy certain pre-requisites. These and the way they contributed to the construction of the questionnaire is described next.

Given that, originally, the research plan included the comparison of the results obtained with the questionnaire and with the computer games, the design of the questionnaire was, also, influenced to some extent by features taken from the computer games.

4.1.2 Pre-requisites of the questionnaire

There were three main pre-requisites.

(i) Attempt to approach students with less 'formal' and 'academic' situations. This helped to determine the choice of the topic of the questionnaire, the formalization of the questions to be asked and the kind of situations to be presented.

Despite the criticisms made in Chapter 2 about the focus of existing studies being curriculum topics, it was decided that the questionnaire would be centred on the concept of force, more specifically on the existence of forces in given directions. It was also decided, however, that the questionnaire would not ask about particular kinds of forces, such as gravity or friction. Two reasons which lead to the choice of a curriculum topic were, (a) the non existence of any theory of the content of students' everyday knowledge about dynamics which would suggest more natural basic concepts to investigate and (b) the intention to compare results with others previously found by other researchers. The choice of force directions came mainly from the fact that the computer games also insisted on directions of 'kicks'. Gravity or friction were not asked about directly, on the hypothesis that such concepts would not belong to the more natural and primitive scheme of commonsense knowledge about dynamics.

It was decided that the questionnaire would not ask students questions such as 'what a force is' or 'why is there a force in a given situation'. Instead, it would ask students something less academic and less verbal, namely to consider the existence or otherwise of forces in given directions, in several situations involving moving objects and objects at rest. In other words, the questionnaire is not designed to find out the attributes students may give to the concept of force but, rather, to see what 'forces', if any, students feel a need to consider to account for several kinds of motions.

The choice of the situations and the way to present them was mainly guided by two criteria.

One was that the situations should be taken from everyday dynamical events familiar to students' experiences with the world. Two or three situations were adapted from other researches (e.g. a man diving into a swimming pool). The presentation of the situations consisted of a picture of the whole event with only an introductory sentence describing the event. The choice of a pictorial representation, instead of a propositional one, was made on the belief that the first could recall students' attention to those events more effectively.

The second being that the situations should include a variety of motions, in particular, some which could be seen by students as being similar and others as being different. The task of choosing the kinds of motions to include was not easy because no theory was known about possible factors which may lead persons to group everyday dynamical events. An attempt was however made to include some features which may contribute for such classification. They were, firstly, **objects moving** (e.g. ball moving on the ground) and **objects at rest** (e.g. ball stopped on the ground). Another feature was support, that is to consider cases in which moving objects were **being supported** (including different kinds of supports, such as horizontal, sloping surfaces and objects suspended in the air), **partly supported** (e.g. objects in water) and **non supported** (i.e. objects moving through the air). Another was whether there was an **interaction with an external agent** (e.g. person kicking a ball) and wehre **there was not such an interaction** (e.g. tree at rest on the ground after being chopped by a person).

(ii) Attempt to make less reliance on propositional knowledge. This affected the choice of the structure of the questions to be asked in terms of kind of data to collect.

The decision was to elicit students' ideas by using, mainly, a 'closed' approach, in which students had to choose, from a set of eight directions of forces given, the ones which they thought to exist in each situation. No justification were asked for students' choices.

Besides the non-verbal responses described above students were, however, asked to give also a name for the forces chosen. The purposes of getting this more verbal data were, mainly, to compare students' responses obtained by choosing only directions and by giving names, to contrast our results with others previously found (which, as seen, insisted on verbal data) and to gather further information about the forces chosen.

(iii) Adaptability of the questionnaire to a wide range of students' age and physics background, and particularly, to ensure that the results of several groups could readily be compared. This aspect is nearly met by the considerations given previously. That is the topic chosen seems to be accessible to a wide range of students, as well as the situations seem familiar, and the questions asked appear easy to answer.

An aspect which may have been problematic, at least for the youngest students with no formal teaching on the concept of force, is the task of attributing to a force a given direction. This aspect will be considered in the next chapter. Notice also, that the directions of forces given were chosen in a way which would represent forces one might expect students with several different physics background to choose. For example, there is always a direction along the motion, a downward vertical direction, a direction opposite to the motion.

The format of the questions ensures that the results can readily be compared, particularly because all respondents have to consider the same set of alternatives before giving their replies.

Besides the aspects mentioned above, others included **(a)** the length of the questionnaire, e.g. the questionnaire was designed to fit in the timing of a class (i.e. 50 minutes), **(b)** the kind of analysis to be conducted, e.g. the format of the questions facilitates a quantitative analysis.

4.1.3 General description of the questionnaire

It should first be made clear that two slightly different versions of the questionnaire were used, the initial version being given some improvements. The first (QI), including English (QI.1) and Portuguese (QI.2) versions which are nearly the same, and a second (QII), also in Portuguese, where the main changes were made. They are presented in Appendix I. The following description concerns the general aspects of these essentially similar questionnaires, with some notes on the changes.

The questionnaire consists of an A4 size booklet with the intentions and instructions on the outer covers. QI.2 and QII have, in addition, a first page for the student to fill in some personal details, like her/his name, which were initially destined to allow the comparison of the results found with the questionnaire and with the computer games.

The questionnaire consisted of eight different situations, each represented by a drawing outlining the whole event and a sentence describing it. For each situation, three different instants were indicated by a 'compass' showing eight possible directions of forces, as in the example in Figure 4.1.

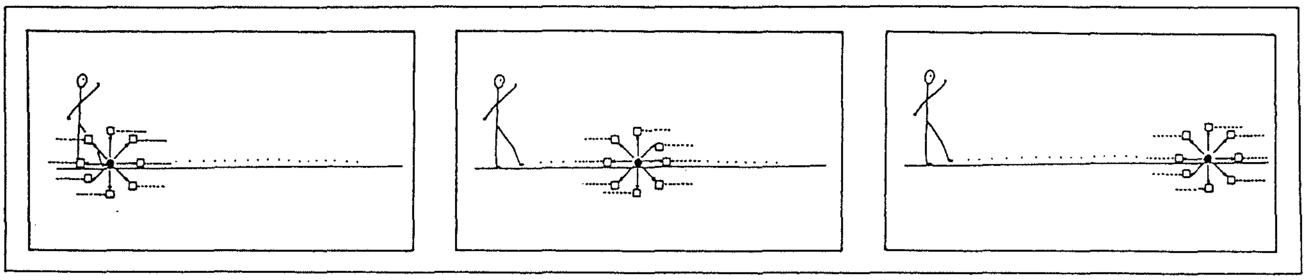


Fig. 4.1 - Example of a situation of the questionnaire (version QII)

The student was asked to choose the directions of forces s/he thought to exist, if any, and give a name to each force chosen or, in case s/he did not know a name to put an **N**. If the student was not sure about the existence or not of a force in any direction, s/he could put an **F**.

The way to fill in the answers varied slightly. In QI each 'compass' direction has a numbered box and the students had to answer by the numbers of the boxes which were given on the top of each 'compass'. A simplified version was chosen in QII, where the students had to fill in directly, near each 'compass' direction.

All the situations are the same in the two versions, except the second and seventh. The changes were made in order to make the situations closer to events familiar to students. Thus, for example, while the seventh situation in QI still looks rather the 'academic' pendulum situation, in QII this problem was possibly overcomed by considering a boxer playing with a suspended ball.

Despite the implications of the changes operated in the questionnaire bring to the analysis of the results, it was decided to make them, given that they were seen as contributing to an improvement of the instrument used. A preliminary analysis was, however, made (see Chapter 5, section 5.2) to consider whether or not the results from the two versions could fairly be combined.

4.2 - Sample

4.2.1 Pre-requisites of the sampling process

As mentioned previously, one of the aims of this research is to investigate further the persistence of students' conception in dynamics, with age and physics teaching. Altough it would be more desirable, for this purpose, to take the same group of students with, say, no formal teaching in physics, and follow it up over time, particularly over several years of teaching, this was not done here for practical reasons. Instead, it was decided to design a cross-sectional study, on the assumption that the comparison of the results of different groups of students with various ages and physics background would bring insights about the issue. Moreover, the research also aims to investigate, to what extent, the methodology used brings some clarification about students' conceptions, that being applicable to any group of students.

Taking into consideration the aspects mentioned above, the following pre-requisites guided, mainly, the selection of the population to be involved in the study:

(a) to include a wide range of students' age and physics background, in particular, from the youngest students without any formal teaching in dynamics up to physics university students at the end of their degree;

(b) to include groups of students with a similar number of years of formal teaching in dynamics but with different ages. Namely, students who had ceased their studies in physics for several years, at a given level, and students who are, at present, at that level;

(c) to include, in any group, a considerable number of students with similar age and physics background.

4.2.2 Description of the sample

A description of the seven groups of students involved in the survey is given next. Each group is designated by a letter (from A to G), which will be used in all the other Chapters. All groups, except two (i.e. F and G), involved

Portuguese students. Groups F and G were English students, chosen partly for convenience of location, and partly because only a very small number (around 5) of Portuguese students were attending a similar level in the university where the researcher had contacts.

The total number of students involved was 338.

Description of the groups

Group A: Portuguese students, average age 14 years old, in their second year of the general secondary school course, without any formal teaching in dynamics in the past or present curriculum (70 students).

Group B: Portuguese students, average age 15 years old, in their last year of the general secondary school course (equivalent to 'O' level in the British Educational System), with formal teaching on the concept of force in the curriculum of that year (69 students).

Group C: Portuguese students, average age 17 years old, at the end of secondary school and attending a science course (equivalent to 'A' level students doing Physics as a subject, in the British Educational System), with formal teaching in dynamics in their curriculum (59 students).

Group D: Portuguese students, average age 20 years old, in the first years of their university degree in Physics and Engineering, with formal teaching in dynamics in their secondary and university curriculum (69 students).

Group E: Portuguese students, average age 23 years old, in the last years of their university degree in Arts, who had ceased their studies in physics at the end of their general secondary school course (at least five years before), that is, at the level of group B (37 students).

Group F: Post-Graduate students taking a Certificate in Physics Education in the U.K. (P.G.C.E. Physics students), with physics formal teaching in their university curriculum (18 students).

Group G: Post-Graduate students taking a Certificate in Biology Education in the U.K. (P.G.C.E. Biology students) with physics formal teaching only in their secondary school curriculum (16 students).

Table 4.1 summarizes the main features of these groups.

Group	Country	Average age (years old)	Level of Study	Current Course	Level of last Formal teaching in dynamics	Number of Students
A	Portugal	14	Beginning Secondary	General	Nil	70
B	Portugal	15	Middle Secondary	General	Secondary	69
C	Portugal	17	End of Secondary	Science	Secondary	59
D	Portugal	20	University	Physics Engineering	University	69
E	Portugal	23	University	Arts	Secondary	37
F	United Kingdom	(not collected)	Post Graduate	Physics Education	University	18
G	United Kingdom	(not collected)	Post Graduate	Biology Education	Secondary	16

TABLE 4.1: Summary of groups

4.3 - Administration

The survey was administered in two studies (study 1 and study 2). Study 1 consisted of two stages. The first (stage I), in October and November of 1982, in which questionnaire QI.1 was administered to groups F and G in a College of the University of London. The second (stage II), in January and February of 1983, in which questionnaire QI.2 was administered to a small scale of students of groups A, B and C in a Secondary School of Oporto (Portugal) and to group D in a Portuguese University. Study 2, in May and June of 1983, in which questionnaire QII was administered to a larger scale of students at the same Portuguese schools as those of study 1. A summary of these field-work stages and the details about the number of students involved in each is given in Table 4.II.

Desc. of the Studies	Groups	Number of Students Involved						
		A	B	C	D	E	F	G
Study 1	**STAGE I** U.K. Oct./Nov. 82 QI.1						18	16
Study 1	**STAGE II** Portugal Jan./Feb. 83 QI.2	14	15	14	69			
Study 2	Portugal May/Jun. 83 QII	56	54	45		37		

TABLE 4.II: Summary of the stages of the administration of the survey

The reason for the studies described was, originally, to test out the questionnaire firstly in a small scale, therefore study 1 (stage I and II), although, for practical circumstances, the questionnaire was administered fully for group D and it was not possible to gather any data from group E.

The administration of the survey was identical in the two studies. It consisted of the researcher asking a class, or a group of students, to complete the questionnaire, after the students had been previously informed about the nature of the enquiry. Particularly that it was part of a research plan intended to find out students' ideas about force, the importance of students giving answers according to their beliefs without any worry concerning school evaluation. All groups aswered the whole questionnaire, except group G which due to time commitments of the teacher answered only the six first questions of questionnaire QI.1. The great majority of each class completed the questionnaire in 50 minutes or less.

Certain limitations of the field work ought to be made clear. These are: groups involving students of two different countries, the somewhat smaller size of group E, the small sizes of groups F and G, and the fact that in the administration of the survey, stage II involved a large scale of group D but no students of group E. These limitations arose primarily from practical difficulties. The effects that these limitations may have had on the results will be taken into consideration in the analysis.

SUMMARY OF THE CHAPTERS 5, 6 AND 7 CONCERNING THE ANALYSIS OF THE QUESTIONNAIRE

The three next chapters present the analysis of the questionnaire (see appendix I) administered to 338 students of seven different groups (see Table 4.1, Chapter 4, sub-section 4.2.2). Generally, the groups were chosen in order to have a wide range of students' age and Physics background. The students are mainly Portuguese, although there are two groups of English students.

The main aim of the analysis is to study students' ideas about the existence (or not) of forces in given directions and to investigate the kind of forces students consider in several different situations which involve everyday events of moving objects.

Two kinds of data were obtained, namely, students' choices of directions of forces and names given to the forces chosen. The main emphasis is, however, given to the first kind of data (attempting to avoid diversity of students' ideas which could arise by language differences). The names given to forces were mainly used to bring additional information to the kind of forces students considered and to investigate to what extent students were able to name the different kinds of forces chosen.

In Chapter 5, general aspects of the questionnaire and its analysis are explored, ending with some considerations about general criteria to be used in the main analysis.

Chapter 6 deals only with the data about directions of forces. The results can be summarized as follows: **(i)** students of the different groups chose definite sets of force directions, including those with no formal teaching in dynamics; **(ii)** there are systematic changes along groups with increase in years of formal teaching, namely students with more years of formal teaching in Physics tend to choose more directions of force in agreement with the Physicist. The notion that a force exists along the direction of the motion, in situations where there is not such a force from the Physicist's point of view, persists, however, for groups with a considerable number of years of formal teaching; **(iii)** groups with similar Physics background but different age and involvement in the process of learning Physics tend to give rather different sets of answers. In particular, students who have ceased their studies in Physics (Arts university students — group E) tend to give similar answers to the students with no teaching in dynamics (group A). These results suggest that (1) students do have definite ideas about what forces exist even if they have not been taught the subject at school (2) although increasing experiences in Physics make some difference, there are notions which persist despite teaching (3) students who have ceased their studies in Physics seem to 'forget' what they have been taught and return to their 'primitive' ideas.

After the overall analysis, the discussion is focussed on the force directions mostly chosen by students. They are: force along the motion, downward vertical force (gravity), force associated with support (forces of support), force opposing motion (forces of resistance) and impulsive forces. A comparative analysis of students' answers in each of these directions is made in order to study how they vary with students' Physics background, age and involvement in the process of learning Physics, and with the situations. Statistical models which best fit the data were found, using Glim.

Chapter 7 deals with names given to forces, that is the second kind of data mentioned above. After a preliminary discussion, a more detailed analysis is given of names given to the force directions. Special attention is given to whether names attributed to forces were as expected and to names of forces which do not agree with the direction of force chosen.

CHAPTER 5

PRELIMINARY CONSIDERATIONS CONCERNING THE QUESTIONNAIRE AND ITS ANALYSIS

This chapter tackles two problems concerning the questionnaire. One is the general question of the validity of the questionnaire. The other is the problem of whether or not one should combine the results from the two versions of the questionnaire used.

Generally speaking, the instrument used attempts to measure a construct which is not very well defined, i.e., students' **intuitive** ideas about the existence (or not) of forces. However, given the importance of gathering evidence which provides some confidence in the instrument, and so supports the analysis to be done, it seemed appropriate to carry out a sort of 'empirical test of validity'. This 'test' consisted, in essence, of finding out to what extent students gave answers according to what was actually asked and, when this did not occur, to categorize possible cases of answers which nevertheless contain useful information about students' ideas. If the number of these problematic cases is not too large, say less than 20%, one may decide that the questionnaire gives sufficiently meaningful results to deserve further analysis.

Another aspect concerning the meaningfulness of the results, refers to the frequency of F answers given (see p.60). Should a large number of F answers be found, the results would be weakened in terms of students' ideas about what forces exist in the given directions.

The second question addressed in this section, of whether or not one should combine the results obtained in the two version of the questionnaire, arises for practical reasons. Although the variations made on them were not large (see Chapter 4, sub-section 4.1.3), it was decided to compare the results found in both studies before taking any decision to combine them. The results of this investigation are presented in section 5.2.

Finally, in section 5.3, a summary of the decisions taken concerning the main analysis is given.

5.1 – 'Validity' of the Questionnaire

5.1.1 Problematic cases

A first inspection of the answers was carried out in order [1] to find out to what extent students replied to the questionnaire as intended, [2] to categorize possible cases in which the answers present characteristics other than those for which the questionnaire actually asked and define how to treat them in the main analysis.

By an answer as 'intended', is meant an answer in which either the student chose a discrete set of directions with a 'force' in each direction chosen, or chose no directions, meaning that there were no forces. Besides this kind of answer, I have been able to categorize other cases, described below. Proposals for dealing with such cases are also given.

Case 1 – 'undirected forces'

This case includes answers in which the students did not attribute to a force a unique direction.

Notice that a considerable number of such cases would 'invalidate' in someway the questionnaire, as it attempts to study the existence or not of forces in given directions.

Three different sub-cases of **case 1** are specified below as, although they will be counted together for the purpose of this discussion, they will be treated differently in the main analysis.

(a) **'Global forces'/'forces with no direction':** This sub-case includes answers in which the students chose all directions at a particular instant, giving the same name for the force (or N in all directions), and answers in which the students did not choose any arrow although they specified that there is a force, but did not know to which arrow it corresponds.
Although these answers do not attribute to the force a particular direction, they do indicate that there is a force. Therefore they are counted, not as forces with a particular direction, but are kept apart as 'Undirected forces' and discussed in sub-section 6.2.1.6.

[b] **'Multiple directions for the same force':** This sub-case includes answers in which, although the students chose, generally, a discrete set of directions, they attribute to the same force more than one direction. The most common cases are answers in which opposite arrows in the same orientation are chosen for the same force [i.e. ←·→], and clusters of directions [i.e ↙↓↘]. In the overall analysis of directions of forces these cases will be counted but they will be distinguished later in Chapter 7.

[c] **'Mixed outcome':** This sub-case includes answers in which the students chose all or almost all directions for a particular instant, but added to some of them named forces in a definite direction and/or named forces in more than one directions, putting N or F for all the other arrows. In the overall analysis of force directions these answers will be included. The choices where a named force acts in more than one direction will be, however, distinguished in Chapter 7 and they will be included together with the cases mentioned in [b]. Given that these answers also indicate that students chose all or almost all directions, they will also be included together with the cases mentioned in [a] and discussed in sub-section 6.2.1.6.

Despite the fact that the sub-cases mentioned present characteristics other than those which the questionnaire actually asked, it was decided to count them in the analysis as they contain useful information about students' ideas of forces. The cases which will be described next, with an exception for **case 2**, differ from those above, as they indicate in some way that the students misunderstood what the questionnaire asked. For this reason the answers will be left out of the analysis.

Case 2 – 'Components of forces and net forces'

This case includes answers in which the students chose some particular arrows and named them as either component of forces or as net forces.

Although the questionnaire asked for forces and not components of forces or net forces, it was decided to count these answers but a reference will be made, in the analysis of the names for forces [Chapter 7], to their occurrence. The reason for this decision is that, as suggested in the literature [e.g. Viennot, 1983], students may give 'scientific words' to justify their intuitions. In fact, students did name components and/or net forces where they do not exist, from the physicist's point of view.

Case 3 – 'Direction chosen but no force'

This case includes answers in which an arrow was chosen, but the name given suggests that the student thought that there was no longer a force acting in that direction.

For the purpose of counting directions of forces chosen, these answers will be left out of the analysis, as they do not indicate that a force exists. They will, however, be discussed further in Chapter 7.

Case 4 – 'Forces acting on other objects'

This case includes answers in which an arrow was chosen but the name given indicates that the force acts on an object other than the one specified in the questionnaire.

These answers are excluded from the analysis since its purpose is just to count forces acting on the objects specified. Reference to them will, however, be made in Chapter 7.

Case 5 – 'Misunderstanding of the event'

This case includes answers in which the names given indicate that the students misunderstood the event presented in the questionnaire. For example, the name given to the force acting on an object suggests that the object is moving, when the questionnaire says that the object is not moving.

For the purpose of the analysis these answers will be excluded, as they do not correspond to the intended perception of the event.

Case 6 – 'Misunderstanding of the way to answer'

This case includes replies which suggest that the students misunderstood how to answer, for instance, when a student chose only arrows in the first instant of the motion, but the names given refer to the other instants of the situation.

These answers will be excluded from the whole analysis.

Having given a detailed description of each case of problematic answers, we can now see how many there are of the various kinds. These will include: (1) all the replies found for **case 1**, that is, the sum of the replies found for each su-bcase; (2) all the replies found for **case 2**; (3) the sum of all replies found for **cases 3** to **6**. **Cases 3** to **6** are put together as it is proposed to leave them out of the analysis.

Results are illustrated in Fig. 5.1 for group A, choosing this group as critical in that (1) this was the group that, in principle, could have more problematic cases as it includes the youngest students, (2) this was actually the group in which, for the majority of cases, the percentage of problematic answers was largest. Tables with results found in all situations, for each group, are given in Appendix II. The three histograms in Fig. 5.1 indicate the percentage of students' answers of group A in three selected situations, situation 2 - instant 2 (i.e. sit. 2-2), sit. 5-2 and sit. 6-2. Similar results were found in the other situations for this group of students.

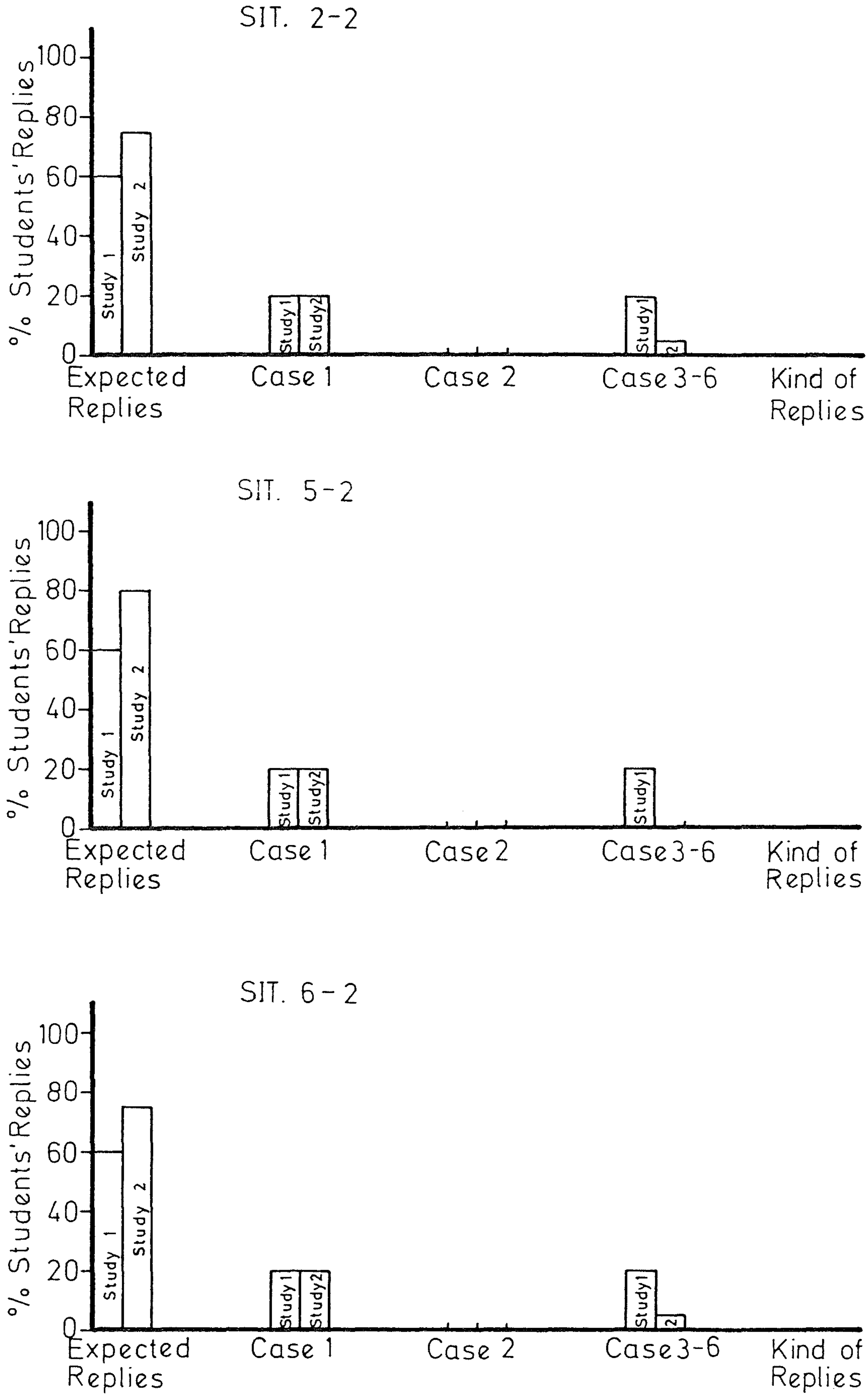


Fig. 5.1 - Histograms of the percentage of students' answers in each case, in three situations of the questionnaire [group A]. The two versions of the questionnaire are shown separetely

The results indicate that: (1) the majority of students gave answers as expected; (2) the percentage of answers for each of the problematic cases is rather small (never higher that 20%); (3) the percentage of answers in each case, in both studies, is not very different. The biggest difference occurs for cases 3 to 6, where the 14 students who replied to the first version of the questionnaire tend to give more such answers than the 56 who replied to the second version, suggesting that the second version of the questionnaire was more understandable than the first one; (4) there are no appreciable differences in the results with respect to the situations of the questionnaire.

These results suggest that the majority of students gave answers as intended, which gives reason to accept the meaningfulness of later analysis of directions of forces. The number of problematic answers is small, and will be reduced by excluding the most difficult cases. So far, we have some evidence to provide a reasonable degree of confidence in the instrument used.

5.1.2 Uncertainty of students' responses

We shall consider now to what extent students were sure about their answers, by looking at answers where students chose an arrow by putting an F on it.

As the questionnaire asked students to choose particular arrows where forces might exist, and to put F on the arrows where they were not sure, the percentage of F answers in each arrow was calculated, for each group of students.

Table 5 - I shows the percentage of arrows corresponding to a specific percentage of F answers, for the different groups of students and studies. Similarly as before, the results found in each study were calculated separately.

Percentage of F answers per arrow	Pergentage of arrows									
	Group A		Group B		Group E	Group C		Group G	Group D	Group F
	STUDY 1	STUDY 2	STUDY 1	STUDY 2	STUDY 2	STUDY 1	STUDY 2	STUDY 1	STUDY 1	STUDY 1
0	80	80	20	20	45	45	85	25	90	85
$>0 \wedge \leqslant 10$	20	20	80	80	50	35	15	75	10	15
$>10 \wedge \leqslant 20$	-	-	-	-	5	20	-	-	-	-
>20	-	-	-	-	-	-	-	-	-	-

TABLE 5 - I: Percentage of arrows and their percentage of F answers, for each group of students and study

The results indicate that the percentage of F answers is rather small, usually less than 10% and never more than 20%. This suggests that students were pretty sure about their responses, which gives further confidence in the questionnaire. Also Table 5 - I shows no substantial differences between the two studies.

Given the small percentage of F answers found, I have decided to leave them out of the main analysis, and so to count only the answers where either students did not choose any arrow or chose one by putting an **N** or a name on it. Proceeding in this way, the conclusions to be drawn from the analysis will be based only on the cases where students were sure about their responses.

5.2 - Two Questionnaires or One?

The need for this discussion arises, as mentioned before, from the fact that the questionnaire used in the first study suffered some changes before it was used in the second study. The risk of combining the results obtained in the two studies is obvious, but the advantages of doing so are worth considering. The advantages of combining the results are (1) for the groups in which students answered both versions of the questionnaire (groups A, B and C), it would increase the size of the sample, (2) for the groups in which students answered only one of the versions (groups D, F and G for the first version of the questionnaire, and group E for the second) it would allow comparison of the results obtained with one version of the questionnaire with those obtained with the other.

The results of the previous section already give some evidence to support a decision to combine the results by showing that differences, between the percentage of kinds of students' replies and of F answers, in both studies were small. However, those results did not show anything about the specific answers given by the students in terms of choices of directions of forces, which we shall consider now. In order to study this factor, the percentage of students' choices of each arrow, in all situations of the questionnaire, were found and compared for the groups where students answered both questionnaires.

Table 5 - II shows the general results found, for each group, in terms of the difference in percentages of students' replies in each arrow for the both studies.

Δ% of students' replies in both studies	Percentage of arrows		
	Group A	Group B	Group C
$\leqslant 20$	85	55	95
$> 20 \wedge \leqslant 30$	10	20	5
> 30	5	25	-

TABLE 5 - II: Differences in percentage of students' choices of force directions in both studies, for the groups answering to both versions of the questionnaire

The figures in the Table indicate that differences in students' replies in both studies are rather small ($\leqslant$ 20%) for the majority of arrows ($\geqslant$ 85%), for groups A and C. For group B there are, however, bigger differences. Notice that, for this group, there are still 25% of arrows in which the difference in the percentage of students' choices of force directions is bigger than 30%. These results suggest that, in general, the differences in both studies had no considerable effect for groups A and C but had some for group B.

There is, however, a factor which could have produced the result for group B, namely the time of the school year in which the questionnaire was applied. The first study was carried out at the beginning of the school year while the second was at the end. Actually, while the students of groups A and C were not in the process of learning dynamics at school, students of group B were. Therefore, the background in dynamics of the students of group B, in both studies, were not the same. Looking at the results found for group B, in both studies, one can actually see that the main differences in the results occur in the arrows which represent directions of forces like gravity and reaction, where students of the second study tend to choose them more than the students of the first study. Fig. 5.2 shows an example which illustrates the point. It refers to one situation of the questionnaire, sit. 3-1: Fig. 5.2(a) corresponds to the results of the first study and Fig. 5.2(b) to the second. The length of each arrow is proportional to the percentage of students who chose a force in this direction. Similar results were found in the other situations.

Sit.3-1 Sit.3-1

(a) (b)

Fig. 5.2 - Percentage of students' choices of force directions in sit. 3-1. Fig. 5.2(a) refers to the first study and (b) to the second study (group B)

Taking into account these arguments, I have decided not to combine the results found for group B in both studies. The results found in study 1 will be left out of the analysis and only the results of study 2 will be kept.

Coming back to groups A and C and to the general results referred to in the beginning of this section, one last aspect will be considered now.

It refers to a more detailed description of students' choices in both studies regarding, in particular, the cases where those differences were bigger.

Fig. 5.3 and 5.4 show, graphically, typical results for group A and C, respectively, in two situations of the questionnaire, namely sit. 3-1 and sit. 6-2. The length of each arrow is proportional to the percentage of students who chose a force in this direction. The diagrams of Figs. 5.3(a) and 5.4(a) correspond to the first study and of Figs. 5.3(b) and 5.4(b) to the second. Similar results were found for all the other situations except three, namely, sit. 2-1, sit. 7-1 and sit. 7-3. These cases will be discussed below.

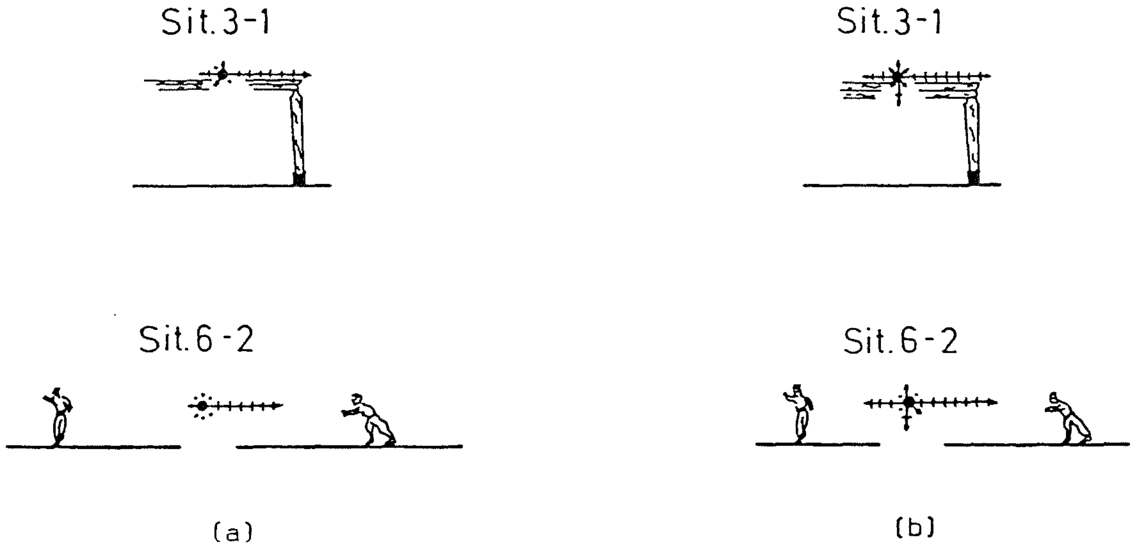


Fig. 5.3 - Percentage of students' choices of forces directions in two situations. Fig. 5.3(a) refers to the first study and (b) to the second (group A)

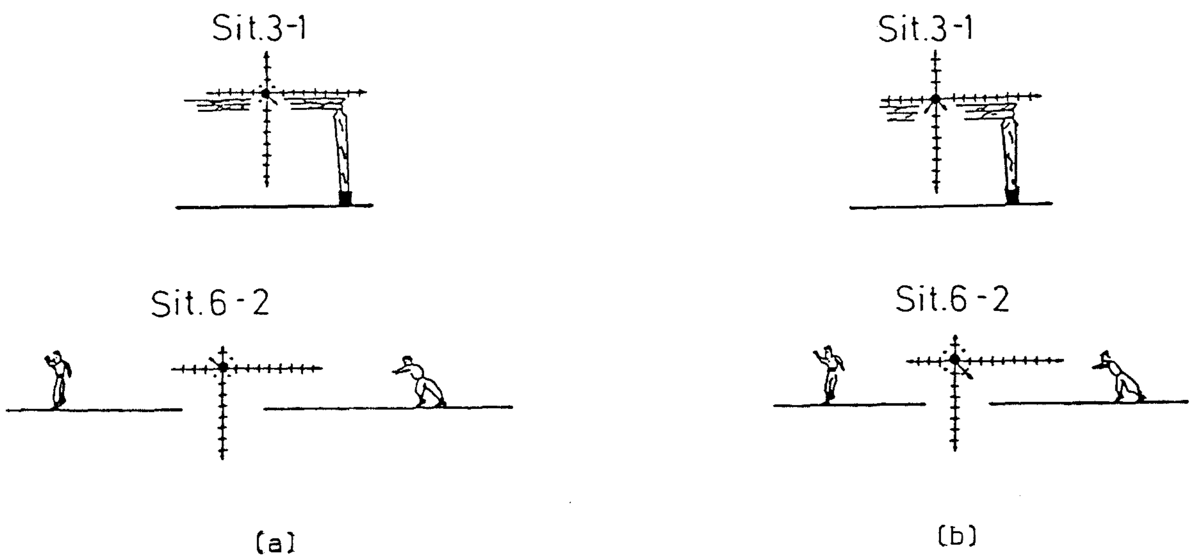


Fig. 5.4 - Percentage of students' choices of forces directions in two situations. Fig. 5.4(a) refers to the first study and (b) to the second (group C)

The results shown in Fig. 5.3 and 5.4 indicate that students' choices of forces in given directions do not differ very much in the two studies. One can see that there are directions which are chosen by a considerable number of students (around 50% and more) and others by a minority (less than 30%). These directions are the same in both studies. The difference in the percentage of students' choices in any direction is never higher than 20%. These results suggest that the changes in the questionnaires have not substantially affected the way students answered them, giving further reason to decide to combine their results.

There are three exceptions to what has been said above, where the results do differ considerably (around 40%) in terms of the percentage of students' choices of a force in a given direction. Those situations are sit. 2-1, sit. 7-1 and sit. 7-3. The directions where these differences occur are, for the three situations, the direction along the motion. These results are illustrated in Fig. 5.5 for group A, being this the group where these differences are biggest.

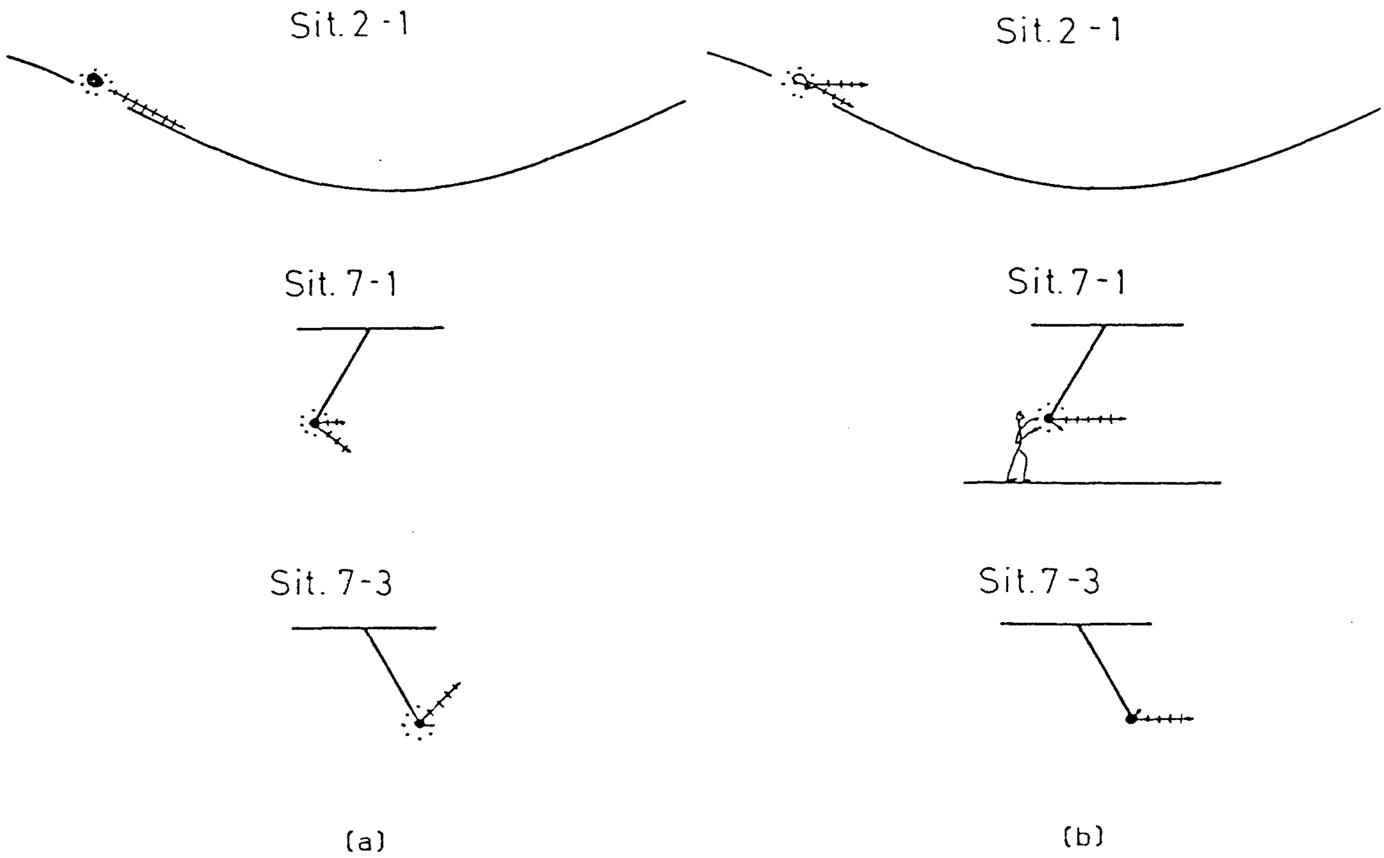


Fig. 5.5 - Percentage of students' choices of a force along the motion in three situations. Fig. 5.5(a) refers to the first study and (b) to the second (group A)

A possible explanation can be given for these exceptions. As can be seen in the two main versions of the questionnaire used (see Appendix I), the arrows along the motion in those situations were differently drawn in the two versions. Thus, for instance, while in sit. 2-1 of the first version (QI.1 and QI.2) there is an arrow along the direction of the motion (arrow 4), in the second (QII) either arrows 3 and 4 could represent the direction of the motion. This ambiguity, caused by a mistake in representing this direction, could have caused the difference found in the results. Considering this fact and the result found that, in all the other situations, the majority of the students chose a force along the motion in both studies, I have decided to count together the choices of the students of arrow 3 and 4, in the second version of the questionnaire, as representing choices of a force along the motion. The outcome of this summation gives a similar result to the other percentages found in the other situations. For sit. 7-1 and 7-3 I will consider the arrow representing the direction of motion differentely in both studies, according to the arrow which better indicates the direction of motion. For instance, the direction of motion in sit. 7-3 will correspond to arrow 2 in the first study and to arrow 3 in the second.

Notice that the procedure described to deal with the answers mentioned, i.e. in sit. 2-1, 7-1 and 7-3 with respect to the force along motion, was also followed for the groups which answered only one of the versions of the questionnaire, in the cases where the problem existed. However, these three instants will be avoided, in the main analysis, when typical results are considered with respect to the force along the motion.

5.3 - Decisions for the Analysis

From the two previous sections, decisions have been taken concerning the 'validity' of the questionnaire and its analysis. They will now be summarized. They are:

(1) to consider the questionnaire as giving sufficiently meaningful results to deserve further analysis;

(2) to pursue the analysis based on students' choices of force directions;

(3) to consider in the main analysis the problematic answers, included in case 1 and 2, which also contained useful information about students' ideas of forces;

(4) to leave out of the analysis the cases which, in some way, indicate that students misunderstood the questionnaire or how to answer it;

(5) to leave F answers out of the analysis given the small percentage of answers of this kind;

(6) to combine the results of both studies, except for group B where only the results of the second study will be considered;

(6.1) to treat differently three instants of the questionnaire (sit. 2-1, 7-1 and 7-3) with respect to the direction along the motion. Namely, in sit. 2-1 to add up the results, obtained in the second study, in arrow 3 and 4 as representing the force along the motion; in sit. 7-1 to consider arrow 4 as representing the force along the motion in study 1, and arrow 3 in study 2; in sit. 7-3 to consider arrow 2 as representing the force along the motion in study 1, and arrow 3 in study 2.

CHAPTER 6

ANALYSIS OF FORCE DIRECTIONS

The aim of this Chapter is to analyse and discuss the results in terms of students' choices of force directions. The analysis to be made here will be concerned with only one part of the data collected, i.e. directions of forces, leaving the analysis of the names to Chapter 7. This approach to the analysis may help: (1) to see to what extent one can reduce diversity in students' answers by avoiding the language factor; (2) to see to what extent names given differ from what one expects when analysing students' ideas through their choices of force directions; (3) to see to what extent students are more sure that a force exists than what to call it.

The first part of this Chapter (section 6.1) presents an overall view of the results obtained. They are shown graphically in terms of percentages of students' choices in each arrow, for all situations, and for each group of students. The general properties of the results are then discussed. They refer to the three following questions:

(Q1) **Do students appear to have definite ideas about forces** or, in other words, **do the results show any patterns at all?** And, if so, **what do these patterns generally indicate?**

(Q2) **Are there systematic changes with increasing in Physics Teaching?**

(Q3) **Are there any changes in groups with similar physics background but different age and involvement in the process of learning dynamics?**

The second part (section 6.2) presents the results obtained, in more detail, with respect to the particular directions of forces mostly chosen by the students. A comparison of students' replies along groups and situations is then made. Statistical models to fit the data were found using GLIM.

6.1 – Overall Analysis

6.1.1 – Graphical summary of the data

Figures 6.1 – I to 6.1 – VIII show the results obtained, in each situation, for all groups of students in terms of the percentage of students' choices in each of the eight arrows given in the questionnaire. The length of each arrow is proportional to the percentage of students' choices. The groups are ordered (from A to F) by number of the years of formal teaching, and where the groups have similar physics background (i.e. groups B and E, C and G) by age. Each figure refers to a situation of the questionnaire (from 1 to 8) and the results are given for the three instants of that situation. In each figure the results are shown for the seven groups. In Fig. 6.1 – VII and VIII, group G is missing, as these students did not answer situation 7 and 8.

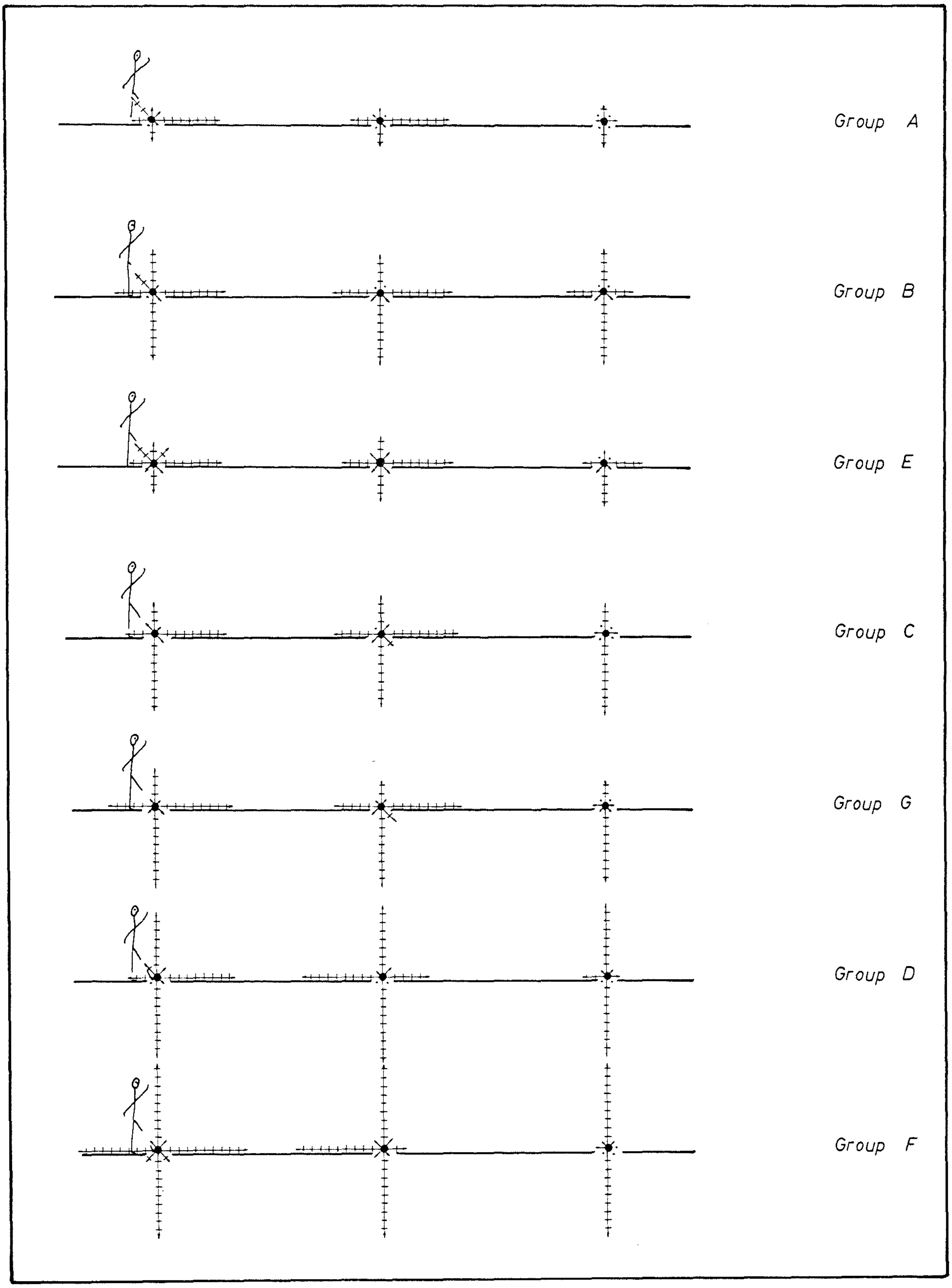


Fig. 6.1 - I: Percentage of students' choices in each arrow of situation 1, for each group

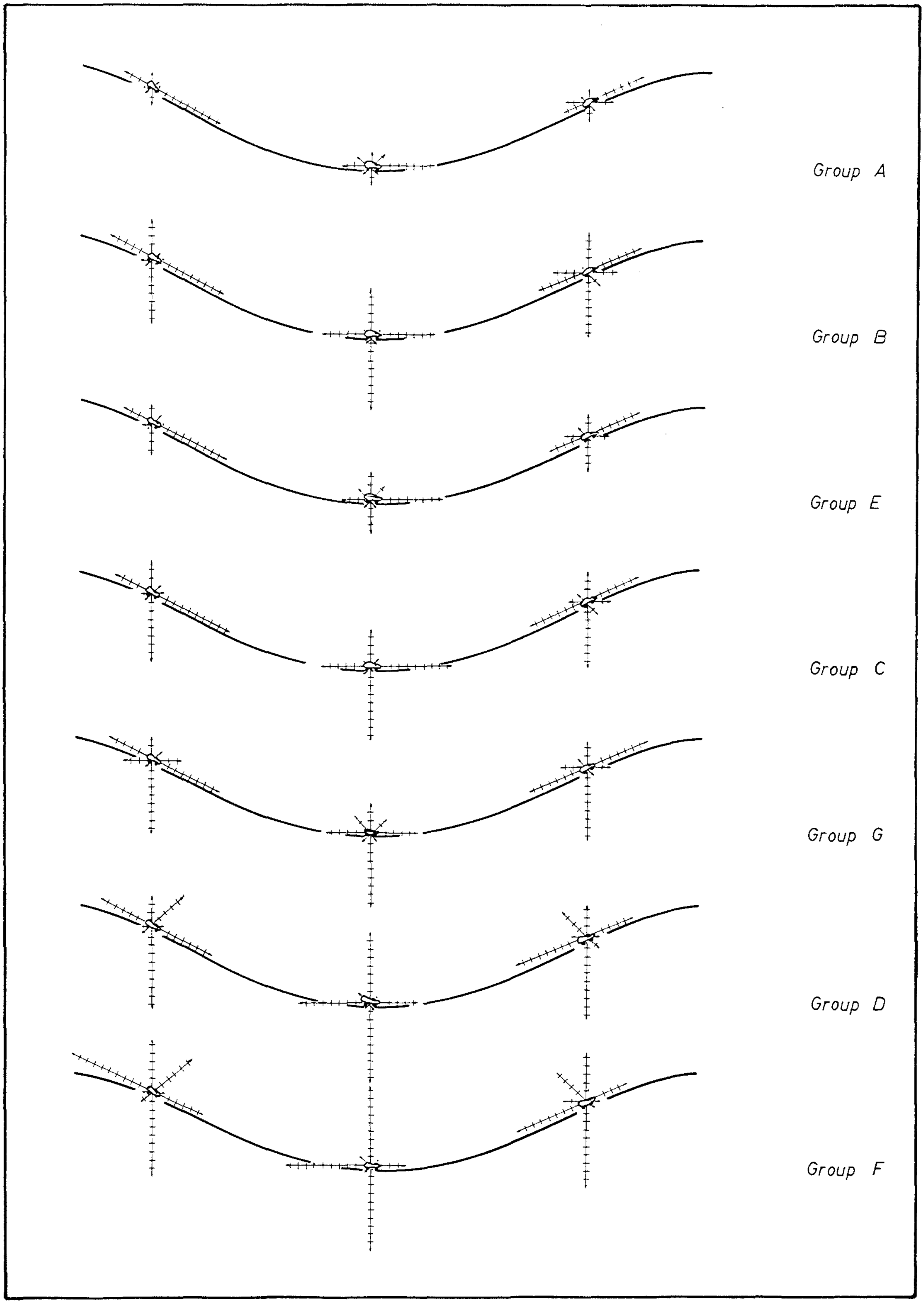


Fig. 6.1 - II: Percentage of students' choices in each arrow of situation 2, for each group

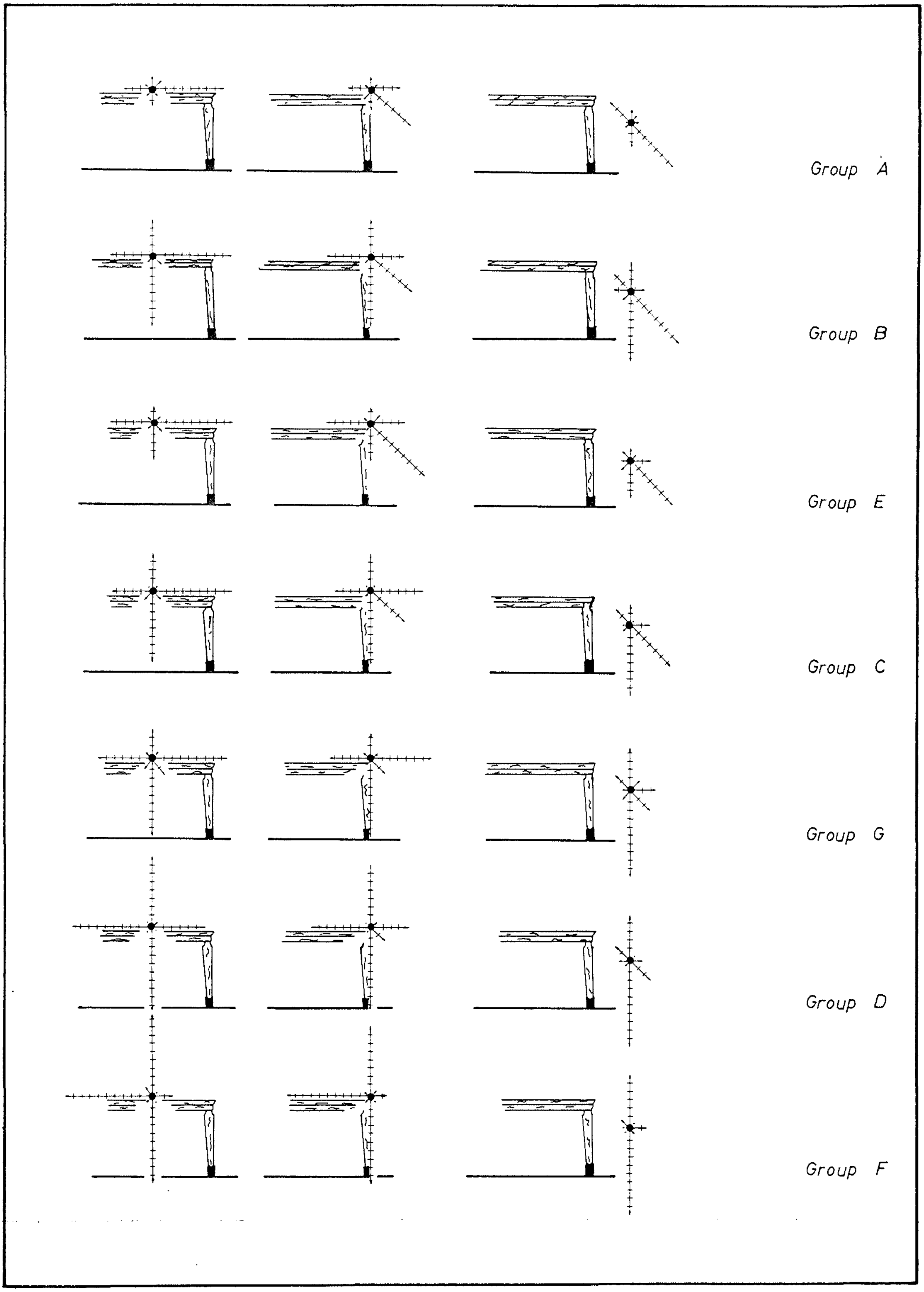


Fig. 6.1 – III: Percentage of students' choices in each arrow of situation 3, for each group

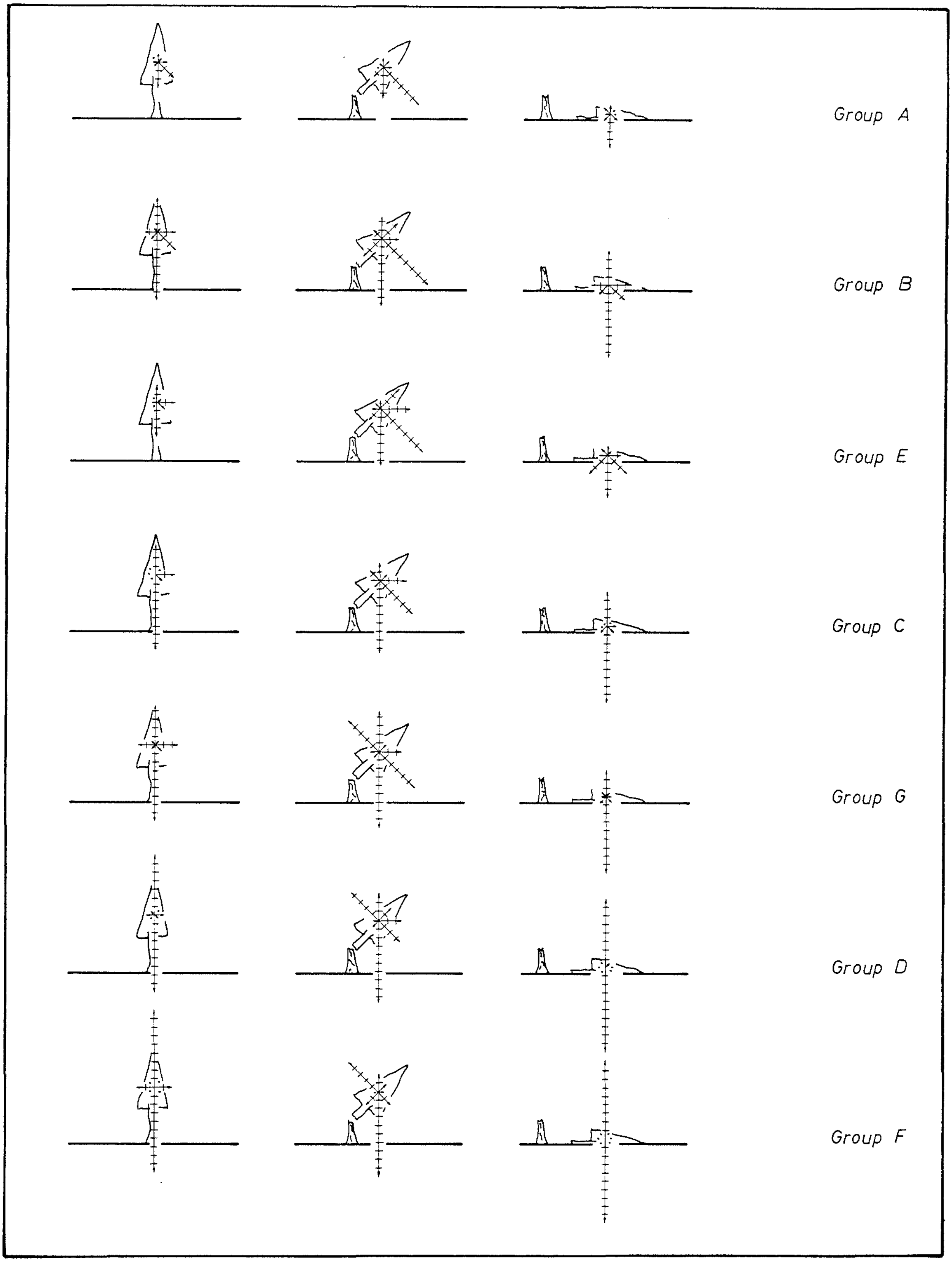


Fig. 6.1 – IV: Percentage of students' choices in each arrow of situation 4, for each group

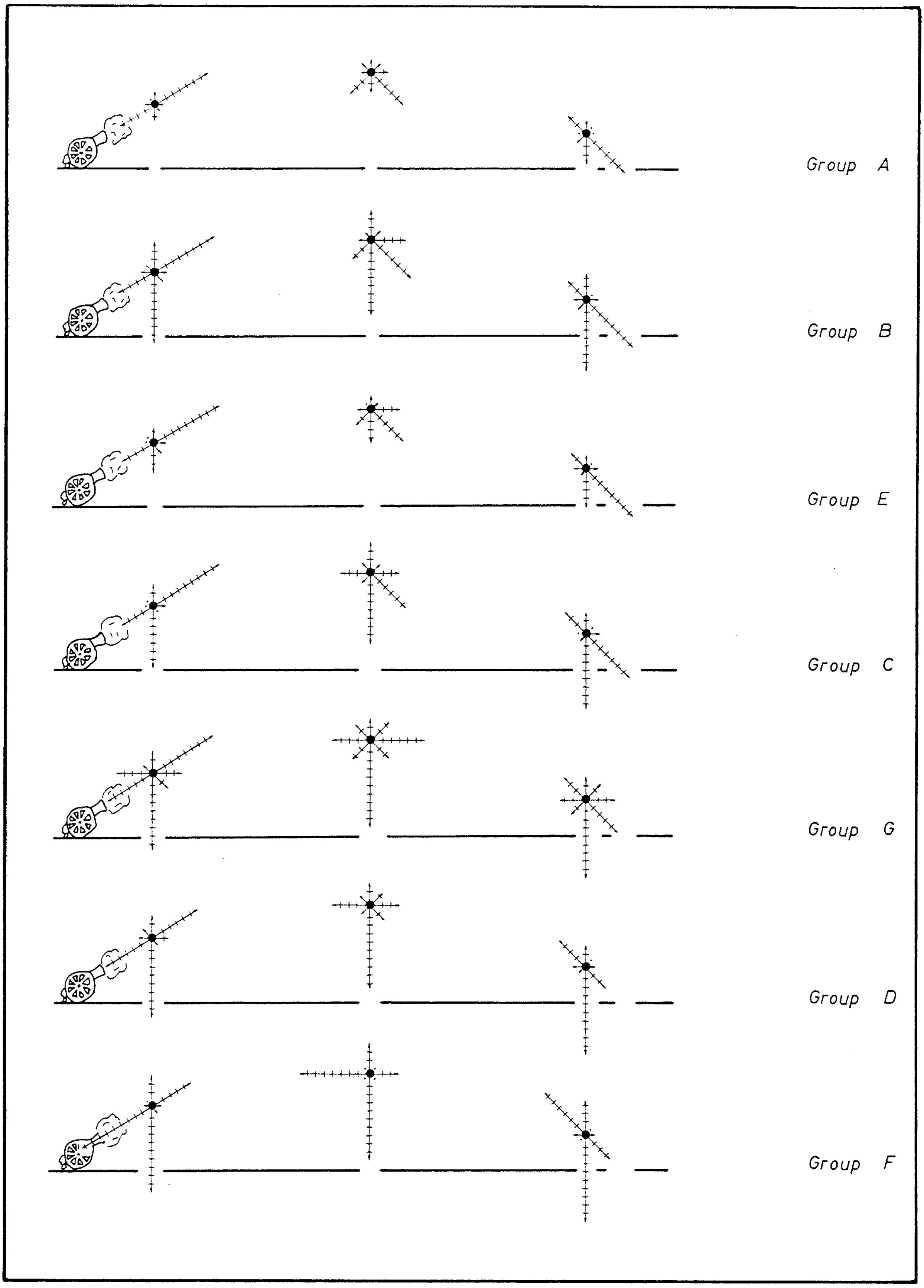


Fig. 6.1 – V: Percentage of students' choices in each arrow of situation 5, for each group

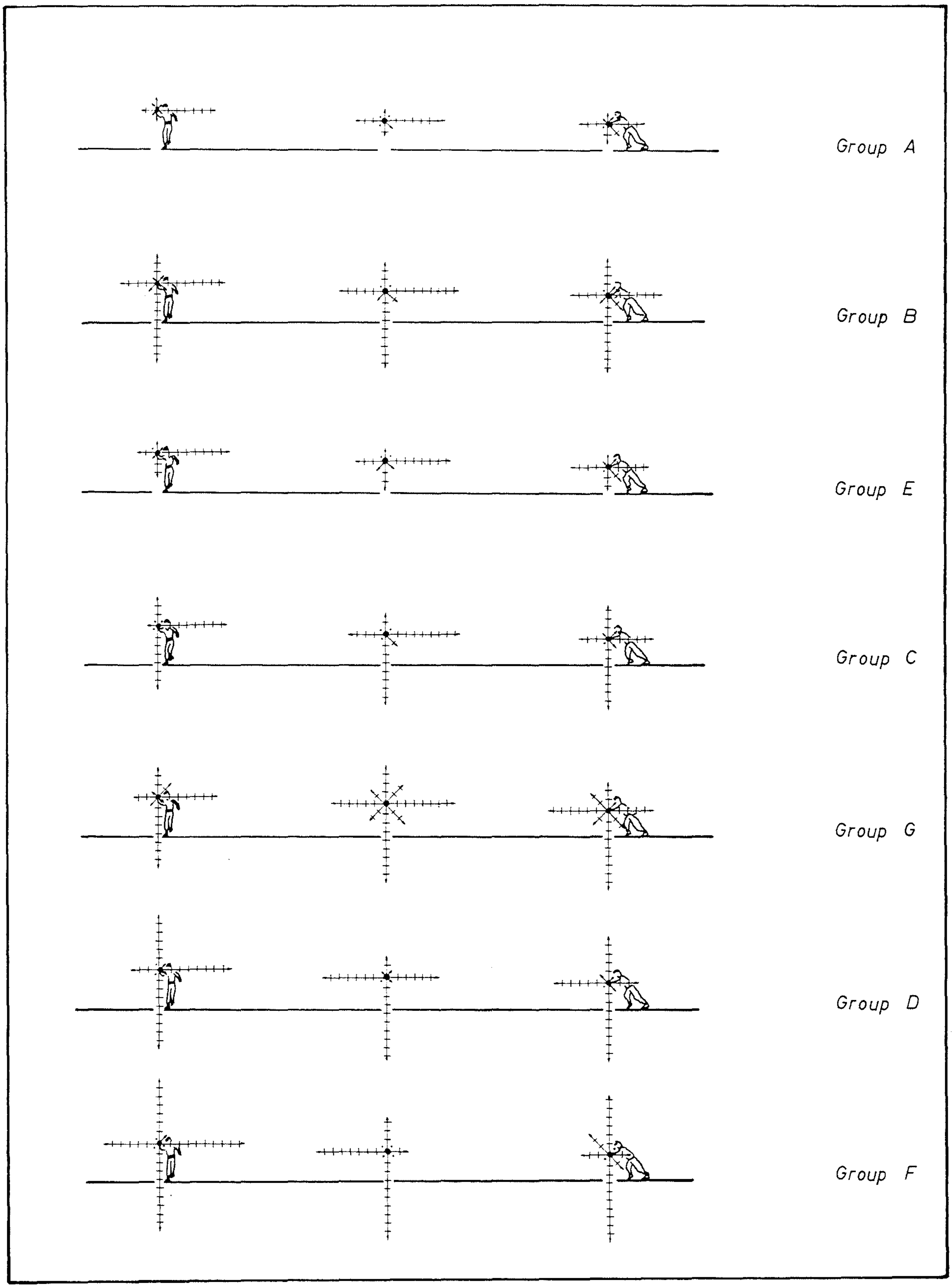


Fig. 6.1 - VI: Percentage of students' choices in each arrow of situation 6, for each group

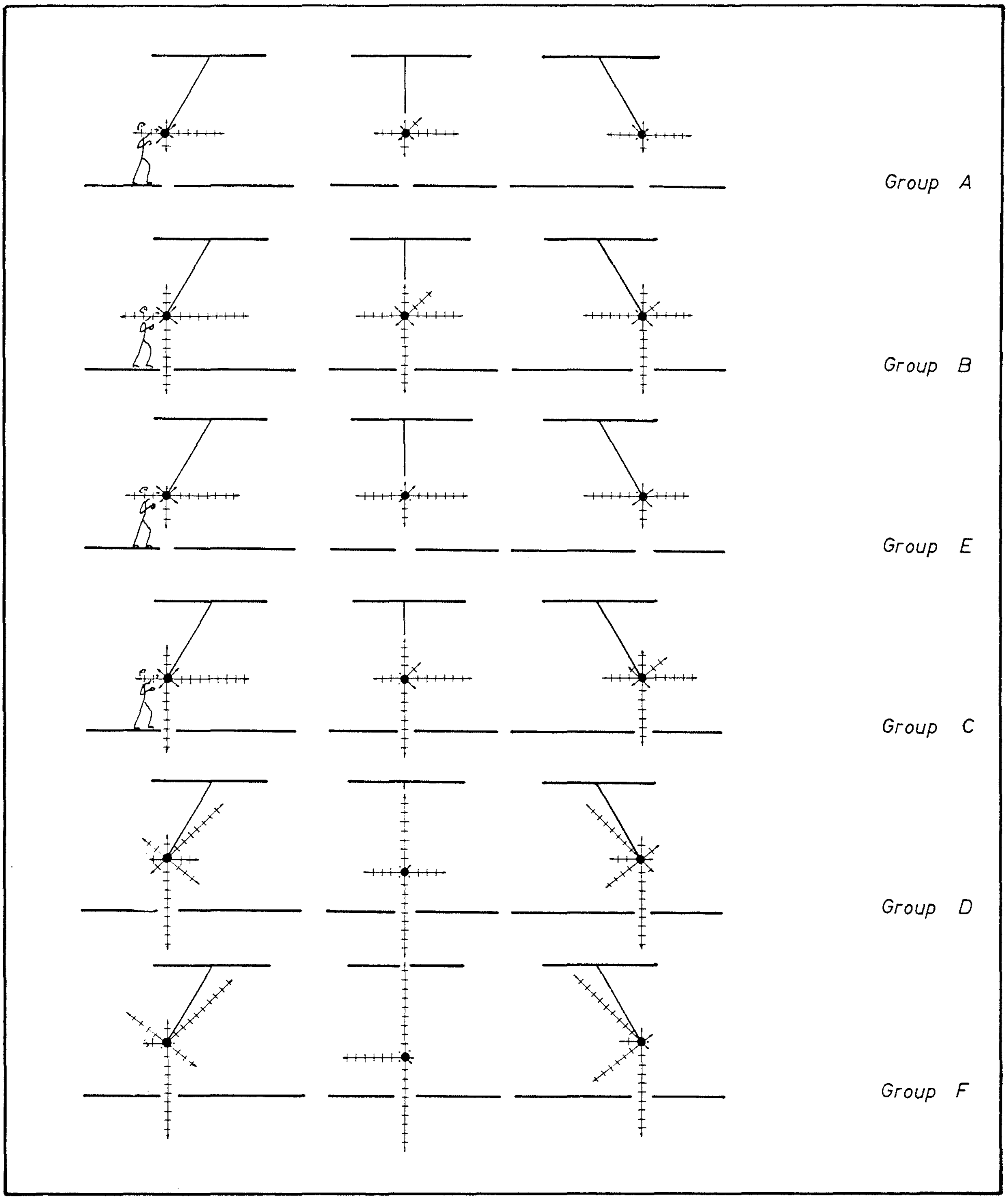


Fig. 6.1 - VII: Percentage of students' choices in each arrow of situation 7, for each group

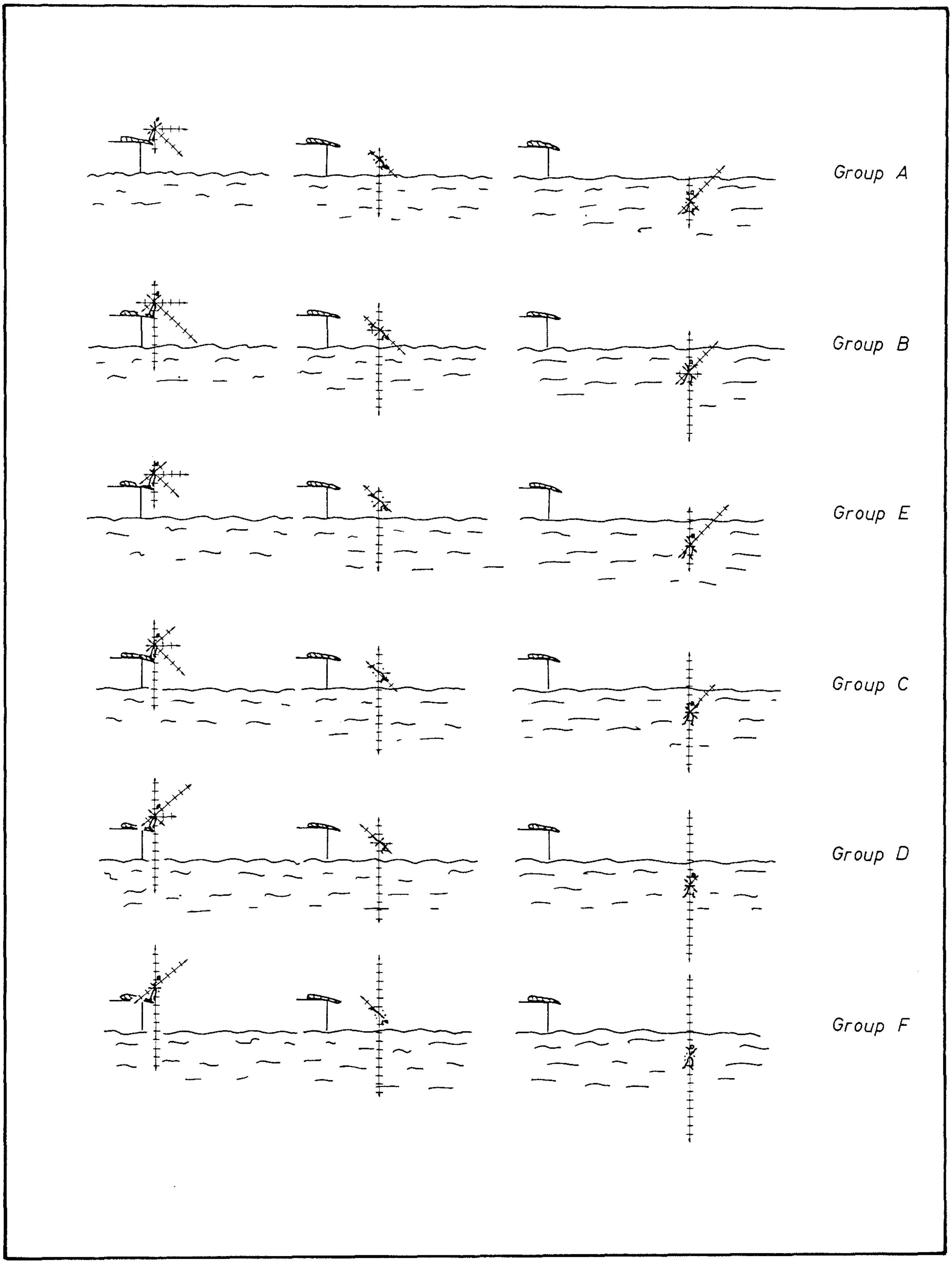


Fig. 6.1 - VIII: Percentage of students' choices in each arrow of situation 8, for each group

6.1.2 – General properties of the results

The results shown in Figs. 6.1 – I to VIII give some insight into the questions listed before.

[Q1] **Do students appear to have definite ideas about forces** or, in other words, **do the results show any patterns at all?** And, if so, **what do these patterns generally indicate?**

To answer the first part of the question, we may note that forces are quite clearly not assigned at random. Generally, there are some directions which are chosen by a majority of the students of a group while others are only chosen by a minority. Notice that this is also true for group A, in which students have not had any formal teaching in dynamics. This result suggests that students do have definite ideas about forces even if not taught, and that these ideas are, generally, shared by the majority of students of any group.

The existence of pupils' ideas about scientific concepts, before any formal teaching has been referred to in recent literature [e.g. Watts et al, 1982] and the results found here bring more evidence to support that with respect to the concept of force.

To answer to the second part of the above question, one may identify what force directions students of a given group, generally, chose. Although the aim here being not to give an exhaustive picture of the patterns which emerged for any group, one notices that students seem to have systematically chosen forces in certain directions under some circumstances. Thus, for example, students of group A generally chose a force in the direction of the motion in situations where objects are moving [e.g. in sit. 1–2, sit. 5–1, sit. 6–2] and no force in situations where objects are at rest [e.g. sit. 1–3, sit. 4–3]. They also chose a force in the direction where a physicist would put an impulsive force, in situations where an external agent is acting on an object [e.g. in sit. 1–1 and sit. 6–1].

[Q2] Are there systematic changes with increasing in Physics Teaching?

To consider the second question, we may compare, for a given situation, the results of each group. There are in essentially all situations similar systematic changes with teaching [from A to F] notably:

(a) increasing existence of a downward vertical force;

(b) increasing existence of a force opposing motion;

(c) increasing existence of an upward vertical force when objects are being supported.

Notice that the increasing of a downward vertical force is much greater than the other two, particularly the upward vertical force. The existence of these forces being in agreement with the physicist, one can say that, in this respect, students with more teaching tend to give more answers according to what they are learning at school. However, if this happens, the results also show another aspect, namely:

(d) persistence of a force along the motion, only reduced for university physics students (groups D and F).

As this force usually does not exist in the situations of the questionnaire from the physicist's point of view, this result indicates that students with experience in Physics keep their alternative view about the existence of such a force, despite the fact that they tend to give other answers in agreement with physics. Generally, these results suggest that teaching does make some differences in students' ideas about forces although it does not remove, despite some years of formal teaching, some of students' alternative views. This aspect of the co-existence of intuitive and 'accepted' views will be the object of further discussion in later analysis. Notice that this aspect has not been much referred to in most recent studies in the area as, usually, the focus of these investigations is students' intuitive ideas only. An example, is the study by Watts and Zylbersztajn (Watts and Zylbertsztajn, 1981) where students were asked to choose only **one** force direction from a set of directions given. However, it seems interesting to investigate further how students incorporate in their framework of ideas, previous to any formal teaching, notions which they are learning in school. Or, in other words and using the terminology of Gilbert and Zylbersztajn (Gilbert and Zylbersztajn, 1985), to investigate 'students' science', i.e. the outcome of the interaction between 'children's science' and 'teachers' science'.

(Q3) Are there any changes in groups with similar physics background but different age and involvement in the process of learning dynamics?

Finally, to consider the third question, we can compare the results of groups with similar background in physics but different age and involvement in the process of learning physics. One can see that, for groups B and E, there are considerable differences in students' answers. In particular, one can see that students of group E, Arts university students who had ceased their studies in physics for some years, tend to give similar answers to the students of group A (students with no formal teaching in dynamics). This result suggests that students with some teaching in physics but who have ceased their studies for some years tend to return to their 'primitive' ideas, 'forgetting' what they had learnt in their physics classes. It also suggests that change in age alone does not succeed in changing students' views towards those of science. This result is in agreement with a study done by Thomaz (Thomaz, 1983).

It is curious that the results of groups C and G are rather similar. There is no obvious way to compare Portuguese school children at the end of secondary school with English graduates training to teach Biology, except to note that if English school children were the same as Portuguese, their new Biology teachers would, in this area of science, know little more than their pupils.

6.2 - Analysis by Particular Force Directions

6.2.1 Comparative analysis of particular force directions

The discussion of the previous section indicated that students systematically chose forces in certain directions under some circumstances. For example, where objects are moving students often chose a force in the direction of the motion. This force does not generally exist, from the physicist's point of view. There are, however, other directions of forces also chosen by students in which, from the physicist's point of view, a force does exist. Some, such as gravity acting downwards, exist in all situations. Others, such as Reaction, exist only in some situations, acting at right angles to the surface on which the objects are placed.

The purpose here is to compare students' views about the five directions of force mostly chosen: force along the motion, downward vertical force (gravity), forces associated with the support (designated here by forces of support], forces opposing motion [designated here by forces of resistance], impulsive forces. This comparison is made with respect to students' physics background, age and involvement in the process of learning dynamics, and to the situations. The analysis of how students' ideas vary with the situations is made according to the classification defined before in Chapter 4, sub-section 4.1.2. Table 6 -I presents a summary of the classification of the situations.

Classification of Situations	Objects Moving	Supported	Horizontal Surfaces	[sit. 1-2, 2-2, 3-1, 3-2]
			Slope Surfaces	[sit. 2-1, 2-3]
			Suspended in the air	[sit. 7-1, 7-2, 7-3]
		Partly Supported		[sit. 8-3]
		Non Supported		[sit. 3-3, 4-2, 5-1, 5-2, 5-3, 6-2, 8-2]
	Objects At Rest (Supported)	Non - Interacting With an External Agent		[sit. 1-3, 4-1, 4-3]
		Interacting With An External Agent		[sit. 1-1, 6-1, 6-3, 8-1]

TABLE 6 - I: Classification of the situations of the questionnaire

The suggestion in the literature that students have an intuitive idea of a 'stored force' with no particular direction [e.g. Viennot, 1979a] is taken up in sub-section 6.2.1.6 ['Undirected' forces].

6.2.1.1 Force along the motion

Fig. 6.2 shows some results for certain situations where objects are moving, giving the percentage of students' choices of a force along the motion for the different groups. The groups are ordered according to years of formal teaching. In none of these situations is there, in fact, any force along the motion.

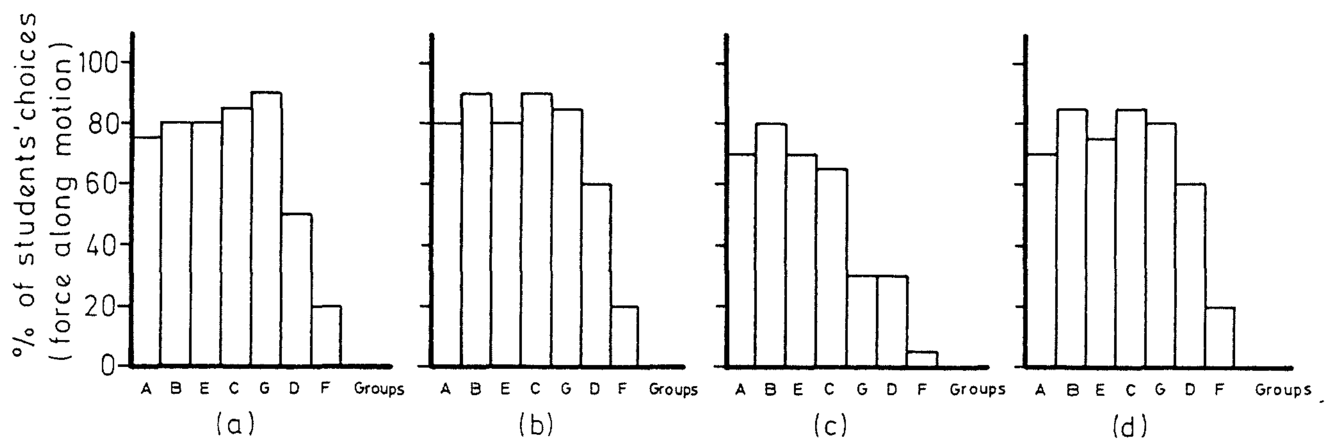


Fig. 6.2 - **Comparison of the percentage of students' choices of a force along the motion, for the different groups, in the following situations:** (a) ball moving on the ground, (b) ball moving on a table, (c) ball falling freely from a table, (d) ball after being thrown by a man

A striking feature of this data is that a force along the motion is chosen by a majority of the pupils (more than 60%) without any teaching in dynamics (group A) and that this proportion remains rather constant, (group B to G) falling only after several years of teaching (groups D, F).

We can conclude that:

(i) the idea of a force along the motion seems to remain quite intact despite any teaching.
This result is in agreement with previous researchers (e.g. Clement, 1982, Viennot, 1979a, Watts, 1983). In the present study similar answers are given to questions by pupils with no teaching and by students with a considerable number of years of formal teaching in physics.

We can also see that:

(ii) despite considerable differences in the situations presented, the frequent choice of a force along the motion is common to all sitations.
This is a quite unexpected result if one follows the hypothesis that students' ideas depend strongly on the nature of the situations presented. In particular, the results suggest that students answer much the same whether the

object is on a flat surface, is falling or has been thrown. Thus, the notion of a force along the motion is not to be regarded as prompted by the kind of situation presented (compare Viennot's model of spontaneous reasoning which suggests that the situation may be influential, Viennot, 1979a).

An important exception is found in the two situations where a change in the direction of the motion is just about to occur (i.e. sit. 3-2 and sit. 5-2). For these, there is a force along the **future** motion rather than along the present motion. Fig. 6.3 compares frequencies of forces along the motion and along the future motion, in these two situations. Notice that, groups with less experience of physics prefer the future direction of motion; whilst those with more, if they chose such a motion-related force, maintain their choice of a force along the current direction of the motion.

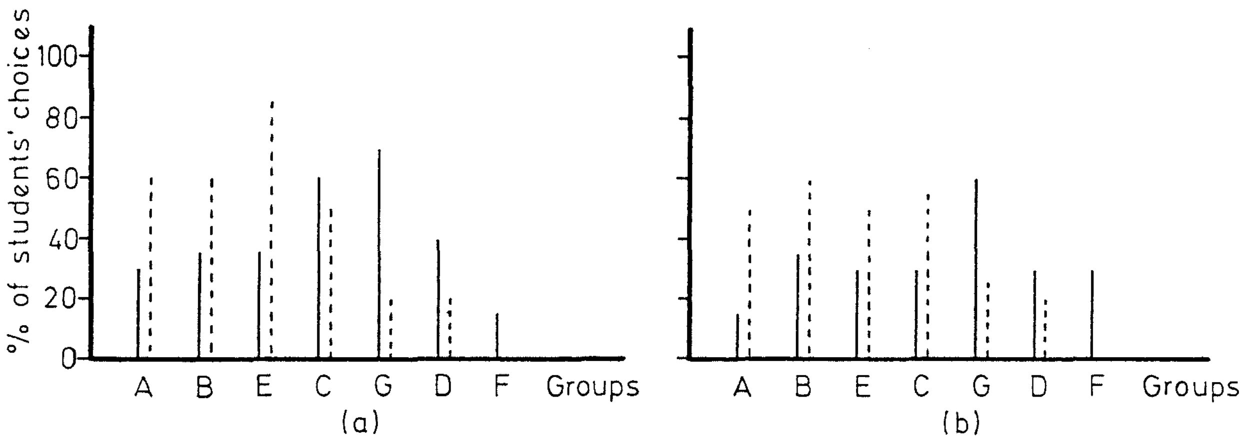


Fig. 6.3 - **Comparison of the percentage of students' choices of a force along the motion (|) and the future motion (¦), for the different groups, in the following situations:** (a) ball on the edge of a table, (b) cannon ball at the highest position of its upward motion

The occurrence of choices of a force along the motion is substantially reduced only for university physics students (groups D and F) and, in some situations (mainly when objects are falling freely) for P.G.C.E. biology students (group G). This reduction is most substantial for physics trainee teachers (group F).

This reduction in the proportion of students who expected a force along the motion does seem to be rather dependent on the kind of situation, thus, a force along the motion tends to persist more in situations where objects are moving and being supported than when they are falling freely. This can be seen by comparing the results shown in Fig. 6.2(a) (or (b)) with (c).

It appears, then, that instruction does modify the idea that a force exists along the motion, but only after some years of teaching. Even so, an appreciable number of university physics students (40% - 60%) still sometimes continue to consider such a force mainly where there is no other force associated with the direction of the motion.

In summary:

- the notion that a force along the motion exists is shared by a majority of pupils with no teaching and persists over some years of formal teaching, despite the fact that this notion is not in agreement with the physicist's point of view. This notion does not seem to vary markedly with the situations except in the cases where a change in the direction of the motion is about to occur. In these cases, students preferred a force in the direction of the future motion;
- although instruction does seem to affect the idea that a force exists along the motion, this only occurs after some years of formal teaching. However, a considerable number of university physics students still continue to consider such a force, but now the idea seems to be dependent upon the situation presented.

6.2.1.2 Downward vertical force (gravity)

From the physicist's point of view a downward vertical force, namely gravity, exists in all the situations. Such a force direction, while often present in the responses, is chosen to an extent and in a way which varies markedly between groups.

The analysis here refers only to the direction of a force rather than to names given to forces, so it can be argued that the choice of a downward vertical force does not necessarily represent, the gravitational force, or that gravity could be supposed to act in other directions. These questions are discussed later, in Chapter 7. Here, simply the frequency of a downward vertical force is considered.

Fig. 6.4 shows, for each group and all situations, the percentage of students choosing a downward vertical force.

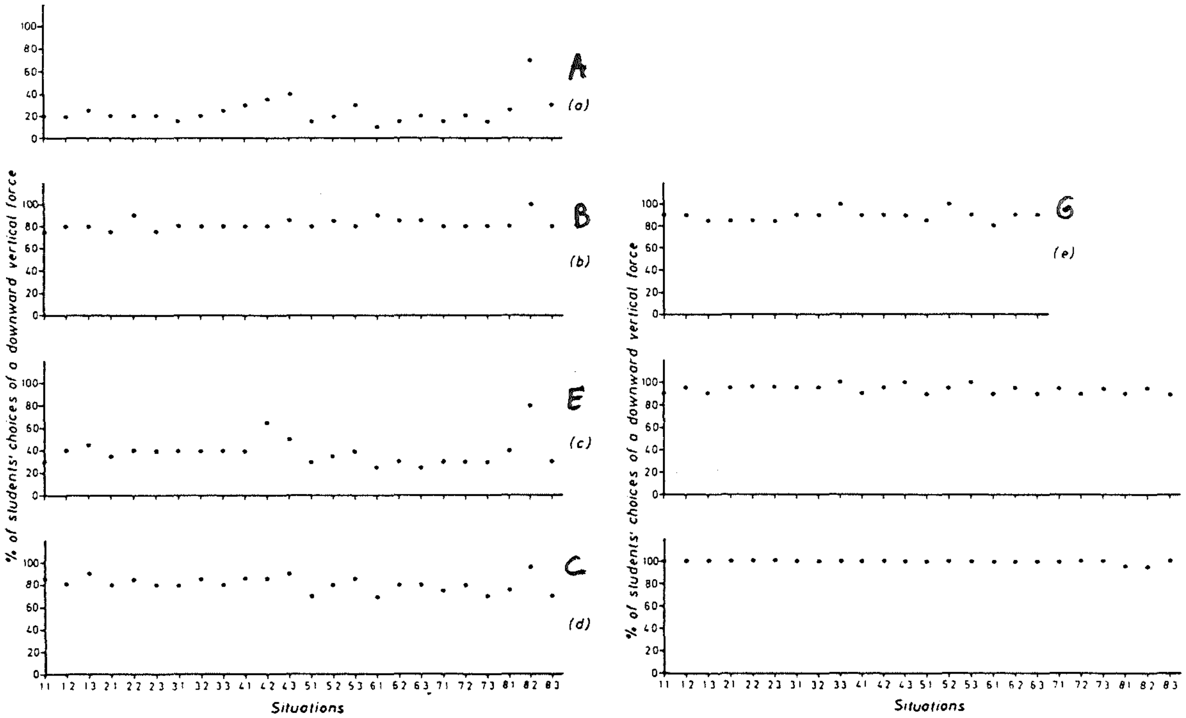


Fig. 6.4 – **Comparison of the percentage of students' choices of a downward vertical force, in all situations, for the different groups, respectively:** (a) Group A, (b) Group B, (c) Group E, (d) Group C, (e) Group G, (f) Group D, (g) Group F

Substantial variations exist in this data. A downward vertical force is not often chosen by pupils who have had no teaching in dynamics (group A) but as soon as they have had some teaching (group B), gravity is at once considered to be present by a majority (about 80%). With more teaching the percentage rises further.

The amount of experience of mechanics teaching is not the only factor which seems to cause variations: its recency also appears to make a difference. Groups B and E have very similar total experience of physics, but students of group E (Arts university students), who have had no teaching of physics for some years, give answers which resemble those of pupils with no teaching in dynamics rather than those of students with recent experience. Here, a small amount of teaching seems to make a substantial immediate difference, but its effects fade with time (at least for students who have, in general, given up any interest in physics).

When a downward vertical force is thought to exist, it tends to exist, for a majority of students, rather universally in all situations. This occurs even for students with little experience of physics (group B). There are, however, small variations across situations for groups with less experience of physics (groups B, C and G). These variations become smaller with increase in teaching (groups D and F).

A special case exists, for groups who do not often chose a downward vertical force (groups A and E), in sit. 8-2, where a man is diving into a swimming pool. Here, a majority of students did choose a force in the downward vertical direction. However, this is also the direction along the motion, and it could be argued, given the evidence presented previously, that this is not a case in which gravity is exceptionally recognized, but that it is a force along the motion.

In summary:

- pupils without any teaching in dynamics do not, usually, consider a downward force in the direction of gravity;
- a downward vertical force in the direction of gravity begins to be considered, by a majority of students, as soon as teaching takes place. With more teaching, the number of students who expect a downward vertical force to exist increases. Despite small variations across situations for groups with less experience of physics a force in the direction of gravity exists rather universally for all situations;
- students for whom teaching in physics finished some years before, tended to answer in a manner similar to pupils without any teaching in physics by not, in general, choosing a force in the direction of gravity.

6.2.1.3 Forces of support

In some of the situations presented, there are objects which are being supported in someway, that is, not allowed to fall freely. The kind of support varies: including objects on the ground, on a table, on a sloping surface, on a man's hand, and hanging from a string.

From the physicist's point of view, a force preventing the object from falling exists in all these cases. This force is called, here, 'force of support'. Forces of support do not always act in the same direction for all situations, nor do they have a unique scientific name. The direction of this force, being at right angles to the surface, is vertically upwards if objects are on horizontal surfaces, but not when objects are on sloping surfaces. In both cases, the force of support is often termed Reaction, in physics. When objects are hanging from a string, the force always acts along the string, changing in direction as the object is moving, and is called the Tension in the string.

The purpose here is to look at the occurrence of students' choices of a force in the direction which a physicist would choose for the force of support.

Fig. 6.5 shows the results in relevant situations. The percentage of students, choosing a force in the direction of the force of support, is given for the different groups. As previously, the groups are in ascending order of years of formal teaching. Fig. 6.5[a], [b] and [c] refer to objects placed on horizontal surfaces, [respectively, the ground, a table and a man's hand] the force of support [Reaction] is, in all cases, acting upwards. Fig. 6.5[d] and [e] refers to, respectively, an object placed on a sloping surface and hanging from a string at an angle to the vertical. Here the force of support is not vertical.

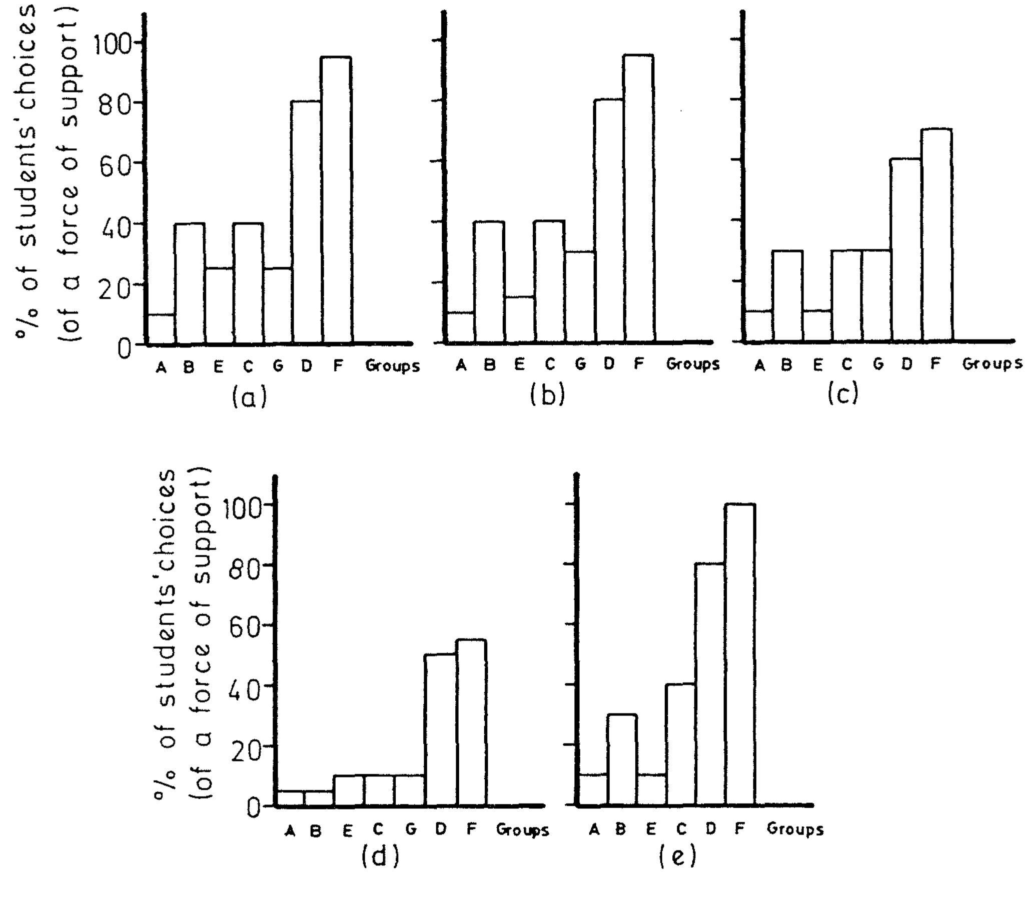


Fig. 6.5 - **Comparison of the percentage of students' choices of a force in the direction of the force of support, for the different groups, in the following situations:** [a] a ball moving on the ground, [b] a ball moving on a table, [c] a ball on a man's hand, [d] a car moving downwards on a sloping surface, [e] a ball hanging from a string

Generally, this data indicates that forces of support only begin to be considered after instruction. Notice that, pupils who have had no teaching in dynamics (group A) hardly ever attribute such a force in any situation. Even with some teaching (groups B, C and G), the porportion of students who do so is no more than a substantial minority (about 40%). A substantial increase occurs for groups with more experience of physics (university physics students of groups D and F), where a majority (about 80%, and more for group F), generally agree with the physicist's view.

As before the recency of teaching appears to make a difference, as it is seen by the previous comparison of groups B and E. Again, group E who have ceased studying physics for some time give responses which are more similar to those of group A (pupils with no teaching) than to those of group B.

The groups who do give forces of support do not answer uniformly in all situations. Thus, for example, Reaction forces tend to exist more when an object is on a solid surface than when it is on a man's hand. This is true not only for students with less teaching but also for students with more experience of physics (see Fig. 6.5(a) (or (b)) and (c)).

In the groups with less teaching more students expect the existence of Reaction forces when objects are on horizontal surfaces than when supported by a string (see Fig. 6.5(a) ((b) or (c)) and (e)).

A substantial reduction of choices of Reaction forces due to solid surfaces, seems to occur for all groups, when objects are on a slope (see Fig. 6.5(d)). An interpretation of this results is, not that students do not expect a 'Reaction' force in this case, but that they continue to consider that the force acts vertically upward. Perhaps students consider that a Reaction force must always balance gravity.

Fig. 6.6 illustrates this last result. Percentage of students' responses are given, for each group, in two different positions of situation 2 (car on a sloping surface), respectively: in sit. 2-2, where Reaction is actually upwards and vertical, and in sit. 2-1, where Reaction does not act in the upward direction.

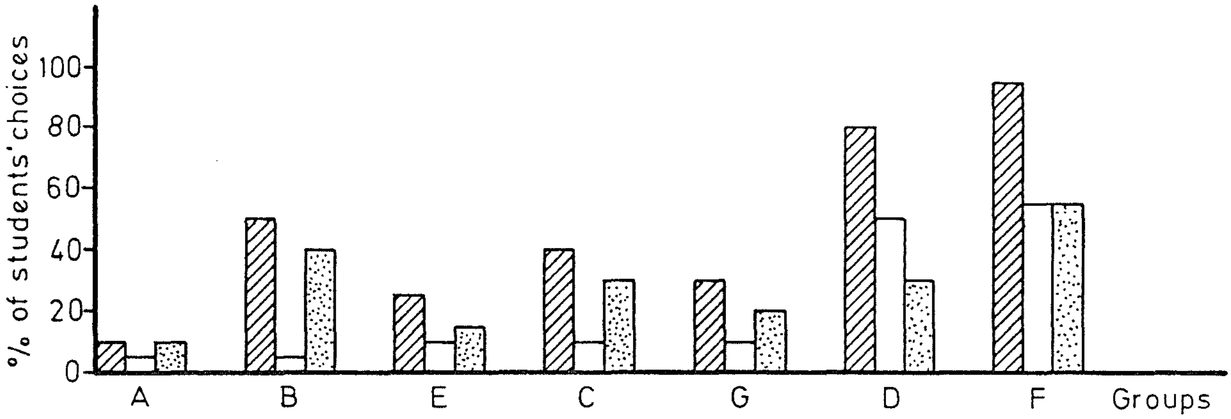


Fig. 6.6 - **Comparison of the percentage of students' choices, for the different groups, of the following forces:** actual upwards Reaction in sit. 2-2 [▨], actual Reaction [□] and upward vertical force [⬚] in sit. 2-1

These results suggest that:

- no substantial difference exists between situations where the Reaction is actually upwards, even if the object is on a sloping surface (compare the results found for sit. 2-2 in Fig. 6.6 and those shown in Fig. 6.5(a) or (b));
- groups with experience of physics continue to choose an upward vertical force in sit. 2-1, where the surface slopes. Notice that, groups with more experience (D and F) chose both directions (upwards and at right angles to the surface) while groups with less experience prefer, mainly, the upward 'Reaction'.

In summary:

- forces of support are not considered, in any situation, by pupils with no teaching or no recent teaching, (groups A and E);
- students' expectations that forces of support do exist increase with teaching. However, a substantial increase only occurs for university physics students (groups D and F). In groups with less experience of physics (B, C and G), a little less than half of the students seem to expect the existence of forces of support in some situations;

- students' expectations about forces of support, differ between situations. Forces of support tend to be more often present in situations where objects are on solid surfaces.

- An upward 'Reaction' continues to exist even in situations where Reaction does not act in that direction (sloping surfaces). Groups with less experience of physics (B and C) tend to recognize Tension forces less often than upward Reaction on solid surfaces.

6.2.1.4 Forces of resistance

From the physicist's point of view, when objects are moving on a surface and/or through the air, there are forces which tend to reduce the velocity of the object. Two very different kinds of forces are involved, surface friction and air resistance. They differ considerably in magnitude, surface friction being generally rather large compared with air resistance. Thus, in the situations where objects are moving on a surface, the force of friction is the one which most contributes to the reduction of the velocity of the object. This force is parallel to the surface and opposite to the motion. Air resistance on objects moving freely through the air acts in the opposite direction to the velocity of the object.

For the present, both forces are referred to as 'forces of resistance'.

Fig. 6.7 shows the percentage of students choosing a force in the direction of the force of resistance, in several situations.

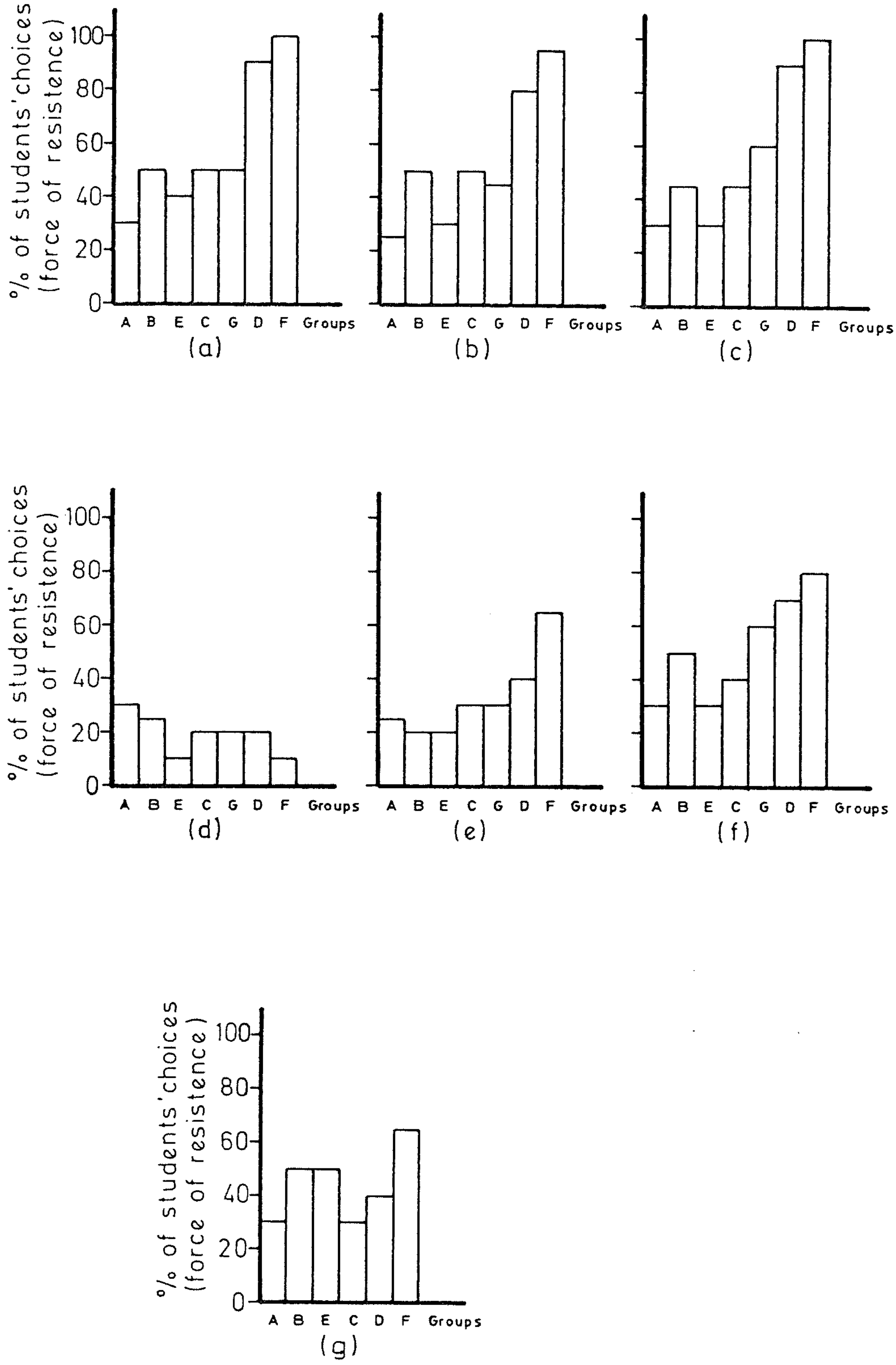


Fig. 6.7 - **Comparison of the percentage of students' choices of a force of resistance, for the different groups, in the following situations:** (a) ball moving on the ground, (b) a car moving on a sloping surface, (c) a ball moving on a table, (d) a ball falling from a table, (e) a cannon ball falling, (f) a ball after being thrown by a man, (g) a ball moving being suspended by a string

Generally, this data indicates that students' expectations about forces of resistance increase with teaching. Pupils with no teaching of dynamics (group A) rarely attribute these forces in any situation. With teaching, the percentage of students who choose them increases, but only slowly, until there is a substantial increase for university physics students (groups D and F), where a majority attributed forces of resistance in at least some situations. Note that once again students of group E (Arts students) chose such forces about as often as pupils of group A (no teaching).

The frequency of choices of forces of resistance is not the same in all situations. Forces of resistance tend to exist, more often and without much variation, in situations where objects are moving on a surface than when objects are moving freely through the air.

For groups with more experience of physics (D and F), the difference between solid and air resistance seems to be quite substantial. Thus, for example, only a sizeable minority of students of group D (about 40%) attributed air resistance forces, whilst a majority of them (more than 70%) chose solid frictional forces (see Fig. 6.7(a) ((b) or (c)) and (d) ((e) or (g)).

An exception to the above is found in sit. 6-2, where a ball is moving freely after being thrown by a man (Fig. 6.7(f)). Here the frequencies of choices of a force of resistance are similar to the situations where objects are moving on a surface (Fig. 6.7(a), (b) and (c)).

An interesting variation occurs in sit. 3-3 (ball falling from a table) and sit. 5-3 (cannon ball falling) which are similar from the physicist's view with air resistance acting in the same direction. However, the results found in the two situations are quite different (see Fig. 6.7(d) and (e)). A further inspection at other force directions chosen suggest that another direction for the force of resistance was probably chosen in sit. 3-3, namely the upward vertical force. Fig. 6.8 illustrates this interpretation. The percentages of students' responses in the two situations are given for each group showing, respectively, choices along the actual direction of air resistance for both situations and choices of an upward vertical force for sit. 3-3.

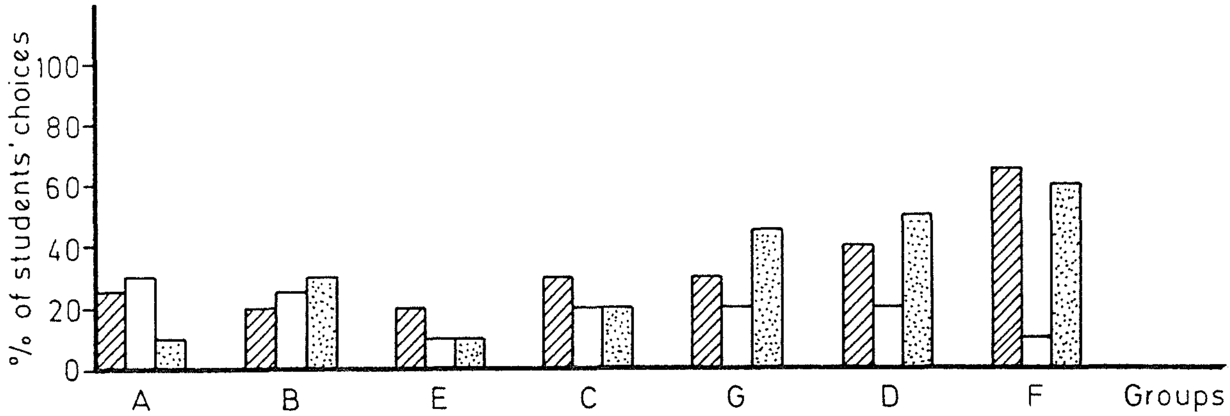


Fig. 6.8 – **Comparison of the percentage of students' choices, for the different groups, of the following forces:** actual air resistance in sit. 5-3 [▨], actual air resistance [□] and upward vertical force in sit. 3-3 [▩]

These results indicate the need to look at other directions likely to be chosen by students for air resistance, namely the upward and vertical direction. If students' answers in both directions (actual air resistance and upwards) are added up, the difference in the occurrence of air resistance choices, compared with solid friction choices decreases very considerably.

In summary:

- forces of resistance are rarely considered in any situation, by pupils with no teaching of dynamics (group A);
- students' expectations that forces of resistance exist seems to increase with teaching. However, a substantial increase only occurs for students with more experience of physics;
- for groups who do give forces of resistance, there are substantial differences in students' expectations between situations, mainly, for groups with more teaching (groups D and F). The more remarkable differences are:
    - solid frictional forces are more often considered than are air resistance forces. However, a reason for this may be that air resistance forces are considered in another direction, namely, upwards;

. attributions of solid frictional forces are more uniformly given, comparing situations, than are those about air resistance;

6.2.1.5 Impulsive forces

Some situations present instantaneous actions on an object where a change in its state of rest (or motion) is about to occur. Examples are: a man kicking or throwing a ball, iniatially, at rest. From the physicist's point of view, this sharp short action (e.g. kick, throw) on an object is a case of applying an impulsive force.

Fig. 6.9(a) and (b) show, for each group, the percentage of students choosing a force in the direction in which a physicist would give for the impulsive force in two situations, respectively, a man kicking a ball at rest on the ground and a man throwing a ball.

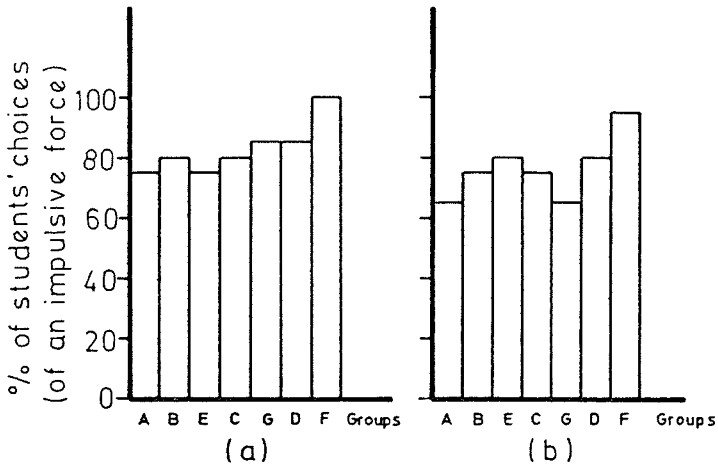


Fig. 6.9 - **Comparison of the percentage of students' choices of a force in the direction of the impulsive force, for the different groups, in the following situations:** (a) a man kicking a ball at rest on the ground, (b) a man throwing a ball

Here students of all groups give essentially similar answers and a majority (more than 60%) agree with the physicist's view. This is true also for pupils with no teaching of mechanics (group A).

There are two other situations where an instantaneous action is supposed to occur, namely, when a man is catching a ball (sit. 6-3) and when a man is jumping from the springboard of a swimming pool (sit. 8-1). The results here are however very different from those above, with frequencies of choices of an impulsive force being markedly reduced, and with larger variations between groups, particularly in sit. 8-1.

Looking at the first case, Fig. 6.10 shows the percentage of students choosing an impulsive force where a man is catching a ball (sit. 6-3), showing a marked reduction in frequency of choices.

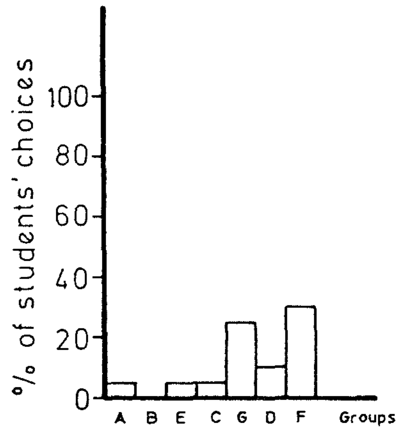


Fig. 6.10 - **Comparison of the percentage of students' choices of a force in the direction of the impulsive force, for the different groups,** when a man is catching a ball

Possible explanation of this result may be:

(a) the picture given in the questionnaire for this situation is ambiguous, it not being clear if the ball is already at rest in the man's hand or is about to stop, i.e. in the instant of catching. If students understood it in the first sense, they would correctly fail to give an impulsive force;

(b) even if students interpretated the situation as intended, an horizontal force, simply in the direction opposing motion may be chosen. Looking at the directions chosen by students for this situation (Fig. 6.11), it can be seen that such a force direction was in fact chosen by a considerable number of students: about 40% and more for groups with some experience of physics (groups C, G and D);

(c) a different interpretation could be that students had shifted the object on which forces were supposed to act, since a forward force could represent the force of the ball on the man's hand, not the force of the hand on the ball. However, students' answers which indicate shifts in the objects on which forces act were as far as possible left out of the analysis [see Chapter 5, sub-section 5.1.1].

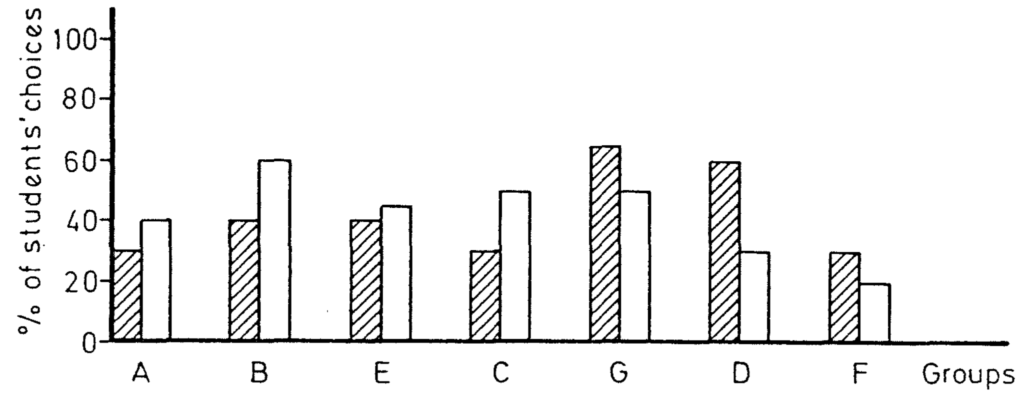


Fig. 6.11 - **Comparison, for the different groups, of the percentage of students' choices of forces in directions associated with the situation of** a man catching a ball, **respectively:** horizontal direction opposite to the man's hand [▨], horizontal direction towards the man's hand [□]

Taking the second case, sit. B-1, where a man is jumping from the springboard of a swimming pool, the choice of the direction of the impulsive force acting on the man could reasonably have been given as either: vertically upwards or upwards to the right. Thus Fig. 6.12 shows the percentage of students choosing forces in both these directions.

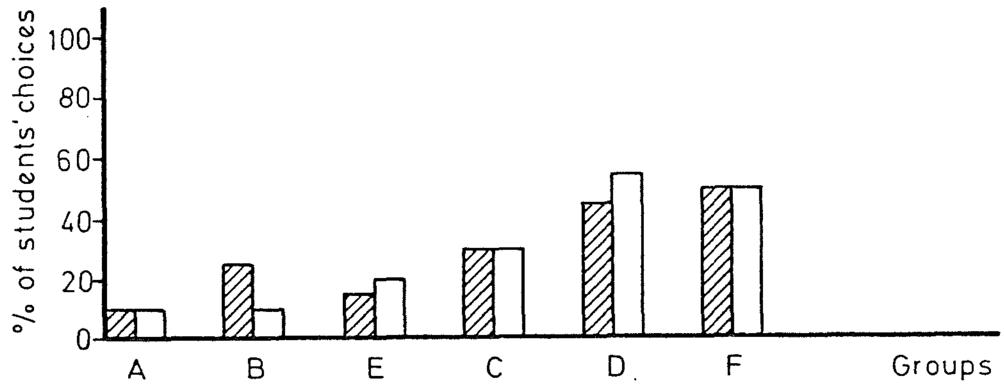


Fig. 6.12 - **Comparison, for the different groups, of the percentage of students' choices of forces associated with the action of** a man jumping from springboard of a swimming pool, **in the following directions:** vertical and upwards [▨], upwards to the right [□]

Adding up students' answers in both directions gives a picture close to that of Fig. 6.9 at least for university physics students (groups D and F). However, without analysing the names for the forces, it is not possible to say whether students' choices of an upward force represent an impulsive force or the Reaction of the springboard.

The reduction in students' expectations of impulsive forces in this case also exists for students with no or with some teaching of mechanics (groups A to C). Looking at other directions of forces chosen by them one notices the popularity of choices of horizontally forward forces and of forces downward and to the right (see Fig. 6.13). Forces acting in such directions can be related, in someway, with the action of the man but it is difficult to see how they can be associated with the action of the springboard. Again, the interpretation of this result requires an analysis of the names students gave for these forces.

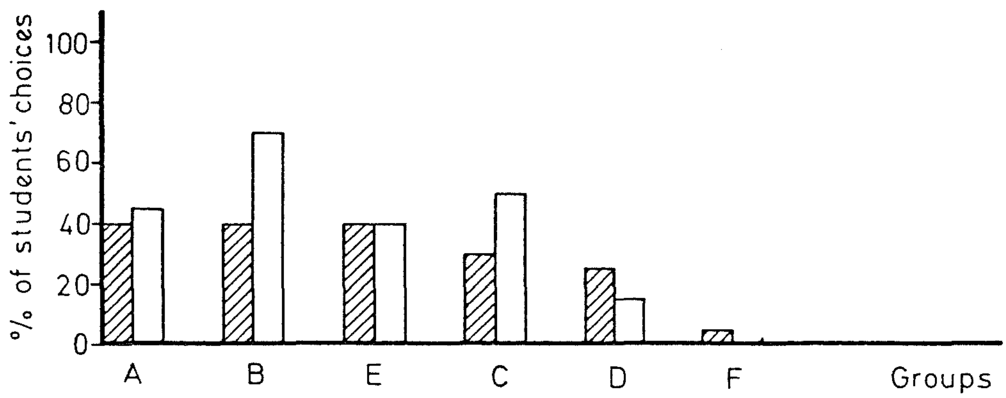


Fig. 6.13 - **Comparison of the percentage of students' choices, for the different groups, of forces acting** on a man jumping from the springboard of a swimming pool, **in the following directions:** horizontal forwards (▨) and downwards to the right (□)

In summary:

- even without instruction, impulsive forces exist in agreement with the physicist's view, at least, if they refer to kicks (or throws) given by a more massive object (e.g. man) to an object (e.g. ball).

6.2.1.6 'Undirected' forces

From the point of view of physics force is a vector quantity. However, previous studies (e.g. Viennot, 1979a, Watts, 1983) suggest that sometimes students think force is a stored quantity, quite similar to energy, and do not attribute any direction to it. The present study was not specifically designed to look into this feature of the students' concept of force but some answers may throw some light on it.

In Chapter 5, sub-section 5.1.1., cases of responses in which the students did not give any definite direction to their forces were discussed.

Table 6.II shows a summary of those results, for each group, giving the percentage of students considering 'Undirected' forces.

Percentage of students considering 'undirected' forces	Percentage of situations						
	Group A	Group B	Group E	Group C	Group G	Group D	Group F
0%	-	-	-	5%	-	15%	90%
>0% ∧⩽10%	-	5%	5%	50%	5%	85%	10%
>10% ∧⩽20%	60%	85%	60%	40%	10%	-	-
>20% ∧⩽35%	40%	10%	30%	5%	85%	-	-
>35%	-	-	5%	-	-	-	-

TABLE 6.II: Percentage of students considering 'Undirected' forces, in all situations, for all groups

Generally, the figures in the table indicate that the number of such answers is usually not large. There are, however, some small variations across the groups. The percentage of students whose answers can be seen as resorting to the 'stored' concept of force, in the majority of situations (i.e. ⩾60%) is between 10% and 20% for groups with less experience in physics (groups A and B) and increases a little for the groups who had had some teaching in physics but have then opted for either humanities or biology studies (groups E and G). This percentage is understandably less in the groups who have more experience in physics (groups C and D) and is much less in the case of physics trainee teachers (group F) where, in the majority of the situations (90%), the percentage is zero.

The results, on the other hand, can not be interpreted in a unique way because different sub-cases of 'undirected forces' are involved (see Chapter 5, sub-section 5.1.1). Thus, responses where students answered in terms of a global force, by choosing a force in all directions or by not choosing any direction but referring to the presence of a force, are closer to the concept of 'stored' force. In addition, there are included here responses choosing all directions but adding to it some named forces in a definite direction; and others where students were not sure of the name of the force or even of its existence. The later cases seem less likely to be an outcome of a notion of a 'stored' force. Furthermore the questionnaire insists upon choosing a direction for a force, and it is possible that the number adhering to a 'stored' notion would be different if the questionnaire had been formulated to permit that response.

6.2.2 Statistical models of students' replies concerning the force directions mostly chosen

The analysis given in the previous sections can be seen as generating hypotheses about how students chose particular forces directions and how their choices varied between groups and situations. The present section looks at such choices statistically, to identify significant differences related to group and situation, in the frequencies with which students selected forces in the directions of particular interest described in sub-section 6.2.1.

The frequencies of students' choices are compared, for each force direction, across all groups, and in some cases, certain selected groups of interest.

The frequencies of students' choices are also compared, for each force direction, across several situations chosen to be relevant. Mainly, the two following criteria were defined to select the situations to be considered:

(a) to include, for each force direction, situations where the results are expected to be similar and others where they are expected to be different. For example, in the case of forces of resistance, to include situations where resistance to motion is mainly due to solid friction and others where it is due to air friction;

(b) to exclude situations which presented some problematic aspects, such as situations which may have been misinterpreted, situations where students may have attributed to a particular arrow more than one meaning for the force under consideration, and situations where there were some differences of presentation in the two studies.

In some cases, for a given force direction, frequencies of students' choices were also analysed with respect to certain selected situations of interest in the light of the previous discussion.

Tables 6.III - 1 to 5 show the data to be analysed. The figures represent the frequencies with which students of each group chose forces in each force direction described in sub-section 6.2.1, in the situations selected.

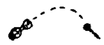
ST / GP	 1.2	 3.1	 2.2	 3.2	 5.2	 7.2	 6.2	 3.3	 5.3
A	50/67	51/65	44/66	21/65	10/67	35/64	48/66	46/65	42/66
B	45/54	48/54	36/54	19/54	19/54	32/53	46/54	43/54	41/54
E	30/37	29/37	28/37	13/37	11/37	24/37	28/37	26/37	28/37
C	50/59	52/59	50/59	34/59	16/59	42/59	51/59	38/59	43/59
G	14/15	13/15	8/15	11/15	9/15		12/15	5/15	8/15
D	36/69	40/69	31/69	29/69	21/69	29/69	43/69	19/69	19/69
F	4/18	4/18	5/18	3/18	5/17	1/17	3/17	1/18	6/17

TABLE 6.III - 1: Percentage of students' choices of a force along the motion, for all groups, in several situations

ST / GP	1.2	3.1	4.1	7.2	6.1	5.1	5.3	3.3	8.3
A	12/67	11/65	19/68	11/64	9/68	11/68	22/66	17/65	19/65
B	43/54	45/54	44/53	43/53	48/54	42/54	45/54	43/54	43/54
E	15/37	15/37	16/37	12/37	9/37	11/37	15/37	16/37	12/37
C	49/59	48/59	50/59	46/59	43/59	43/59	50/59	48/59	42/59
G	14/15	14/15	14/15		12/15	13/15	14/15	15/15	
D	66/69	65/69	64/69	64/69	63/69	64/69	67/69	68/69	64/69
F	18/18	18/18	17/17	17/17	17/17	17/17	17/17	18/18	17/17

TABLE 6.III - 2: Frequencies of students' choices of a downward vertical force [gravity], for all groups, in several situations

ST / GP	1.2	3.1	2.2	6.1	7.2	7.1	2.1
A	7/67	8/65	6/66	6/68	7/64	6/66	3/67
B	22/54	25/54	27/54	18/54	16/53	15/54	3/54
E	9/37	6/37	9/37	4/37	3/37	2/37	3/37
C	22/59	23/59	25/59	19/59	23/59	18/59	8/59
G	4/15	5/15	5/15	5/15			2/15
D	54/69	54/69	54/69	41/69	54/69	54/69	34/69
F	17/18	17/18	17/18	12/17	17/17	16/17	10/18

TABLE 6.III - 3: Frequencies of students' choices of a force of support, for all groups, in several situations

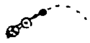
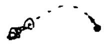
ST / GP	 1.2	 3.1	 2.2	 2.3	 5.1	 6.2	 7.2	 3.3	 5.3
A	19/67	19/65	17/66	17/64	31/68	21/66	18/64	18/65	16/66
B	27/54	25/54	27/54	30/54	24/54	27/54	25/53	13/54	12/54
E	15/37	11/37	10/37	13/36	14/37	11/37	19/37	4/37	8/37
C	31/59	27/59	30/59	39/59	23/59	24/59	17/59	14/59	17/59
G	8/15	9/15	7/15	10/15	9/15	9/15		3/15	5/15
D	63/69	60/69	54/69	57/68	41/69	49/69	30/69	16/69	30/69
F	18/18	18/18	17/18	15/18	16/17	14/17	11/17	2/18	11/17

TABLE 6.III – 4: Frequencies of students' choices of a force of resistance, for all groups, in several situations

ST / GP	 1.1	 6.1
A	50/67	45/68
B	45/54	41/54
E	28/37	30/37
C	46/59	44/59
G	13/15	10/15
D	58/69	54/69
F	18/18	16/17

TABLE 6.III – 5: Frequencies of students' choices of an impulsive force, for all groups, in several situations

The analysis of each table investigates the fraction of choices of a force in the direction of interest as compared with the total number of responses, for each group and each selected situation. This was done by building logit models of the fraction f, where $f = \frac{\text{choices in selected direction}}{\text{total number of choices}}$ using the computer program GLIM (General Linear Interactive Modelling), using a logit link function (logit(f) = f/(1 - f)) and binomial error distribution. From the GLIM analysis the quantity G^2, i.e. the scaled deviance, is determined. This quantity is given by

$$G^2 = 2 \, \Sigma \, f_{observed} \ln\left(\frac{f_{observed}}{f_{expected}}\right)$$

where $f_{expected}$ are frequencies expected for the model being tested. It can be shown that G^2 is asymptotically equal to the X^2 function, so significance values were obtained from X^2 tables.

The analysis of each table takes the same form, and so can be described generally here. The data forms a matrix of fractions, classified by groups of students responding and by situations. Fitting the null model tests whether the fractions of choices of forces in the chosen direction can be regarded as essentially equal for all groups and all situations, apart from random variation. If this model does not fit (large G^2), the presence of systematic differences is indicated.

Next, fitting the model including the group factor tests whether there are systematic differences between the groups, irrespective of the situation. A large decrease in G^2 when this factor is added to the model indicates that there are such differences. Similarly, including the situation factor in the model tests whether the situations differ systematically in attracting responses of a force in the direction being investigated, irrespective of the group.

It may be that the model including group and situation factors fits the data well (say $p > 0.1$), with little G^2 left unexplained. If so, the choices of forces can be said to depend on group and on situation, but without interaction: that is, there is no evidence that particular combinations of groups and situations markedly affect the choice of force direction. The magnitudes of the effects of group and situation factor show how much group and situation alter frequency of choice.

If, however, the model of group and situation factor without interaction is a poor fit, the presence of interactions is indicated. One could fit the saturated model including the interaction factor of **group x situation.** This however would generate a large number of parameters, many of which would be near zero, and which would be hard to interpret. A simpler and probably better approach is to examine the residuals from the model without interaction, paying attention to those which are larger than twice their standard error, and so likely to be real effects. Thus one can pick out combinations of group and situation which deserve attention.

For each force direction, a table will be given showing the values of G^2 (scaled deviance) and df (degrees of freedom) yielded by the GLIM analysis as well as the probability p associated with the fit and also the differences in the value of G^2 (ΔG^2) and df (Δdf) when the effect of group, of situation and of situation + group (ST + GP) is added to the null model. These values will be given, in each case, in the following hierarchy of models: null model, group, situation and situation + group model.

(i) **Force along the motion: all groups and selected situations**

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	606.6	61	<.0005			
GP	387.8	55	<.0005	218.8	6	<.0005
ST	356.2	53	<.0005	250.4	8	<.0005
ST + GP	116.0	47	<.0005	490.6	14	<.0005

TABLE 6.IV: Values yielded by the GLIM analysis with respect to students' choices of a force along the motion, for all groups and all selected situations

From the values given in Table 6.IV, one can see that students' choices of a force along the motion present systematic differences (null model is a bad fit). As none of the other models is a good fit (in all cases p <.0005) one can say that the presence of interactions is indicated. However, G^2 decreases considerably (in all cases $p < .0005$) especially for the situation + group model, indicating that both groups and situations have large effects.

An idea of the magnitude of effects of group and situation is given by the estimates of effects. These estimates are not however very reliable, as the model is not a good fit. By looking at the estimates one can get some idea about the cases which may have contributed to a large value of G^2, which will help to guide the selection of groups and situations in order to find models which fit the data better.

Figs. 6.14 - I and II display, respectively, the distribution of the estimates of effects for each situation and group. Notice that these values are given relatively to situation (1), in Fig. 6.14 - I, and group 1, in Fig. 6.14 - II.

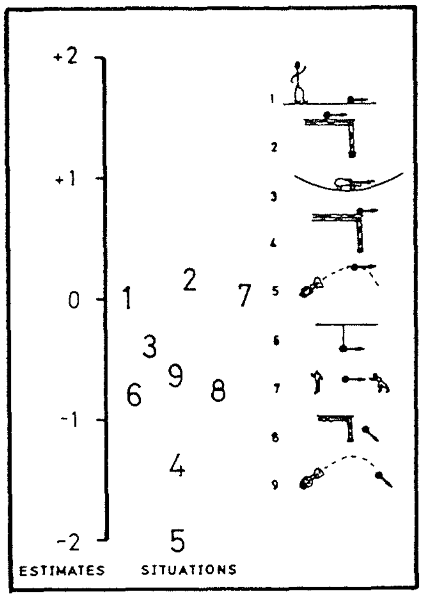


Fig. 6.14 - I: Values of estimates, in each situation, for the ST + GP model, for the force along the motion

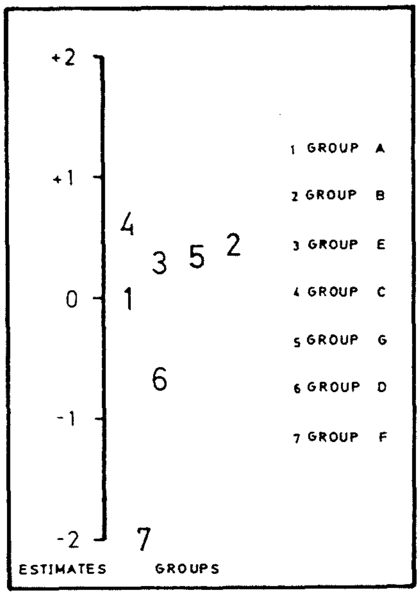
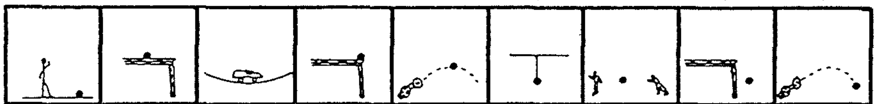


Fig. 6.14 - II: Values of estimates, in each group, for the ST + GP model, for the force along the motion

The distribution shown in Fig. 6.14 - I suggests that there are some situations in which the effects are comparable. Thus, for example, situations (1), (2) and (7) can be regarded as similar, and as those in which students chose a force along the motion more often, as compared with the other situations, mainly [4] and [5], in which students chose that force less often.

Fig. 6.14 - II suggests that although the groups differ, there are two main sets of groups that can be distinguished. One set, including groups [1] to [5], corresponds to the groups which chose a force along the motion more often, and the other, including groups [6] and [7], which corresponds to the groups which chose the force less. This analysis does therefore confirm the previous qualitative discussion, showing that the differences between groups are real.

In order to pick up combinations of groups and situations which deserve attention, the residuals from the situation + group model without interaction will be examined. Fig. 6.14 - III shows the cases in which the residuals are larger than twice their standard error. The sign '–' indicates the cases in which the difference is lower and '+' in which it is higher. The cases in which the residuals are much higher than the standard error, say four times higher or lower, are indicated with a circle around the respective sign.



	1	2	3	4	5	6	7	8	9
A					–			+	
B				–				+	
E									
C					–				
G					+			–	
D				+	+			–	–
F					+				

Fig. 6.14 - III: Extreme residuals found in the ST + GP model, for students' choices of a force along the motion

It is clear from Fig. 6.14 - III that sit. [5] and [8] deserve close attention followed by situations [4] and [9]. In particular, the results indicate that students with less experience in physics, compared with the other groups, tend to choose a force along the motion less when a change in the direction of the motion is about to occur and that they tend to choose such force more when an object is falling freely. On the other hand, the results indicate that students with more experience in physics tend to choose a force along the motion more when a change in the direction of the motion is about to occur and less, than the other groups and in the other situations, when an object is falling freely. Possible explanations for these results can be traced from the previous analysis. As mentioned in sub-section 6.2.1.1, students with less experience in physics tend to revert to choosing a force along the future motion when a change in the direction of the motion is about to occur, this being probably the reason why the residuals are lower in situation (5) (and (4)) for some of these groups. It may be that students with more experience in physics tend to choose a force along the motion less when an object is falling freely, because, in these situations, gravity can explain the motion. Groups with less experience in physics, who did not consider gravity so often, may continue to consider a force along the motion in such situations.

One extreme combination can also be detected from Fig. 6.14 - III, that is situation (5) - group F, where the results suggest that these students tend to choose a force along the motion much more than in other situations and than other groups. As mentioned previously, students of group F tend to choose a force along the motion much less often than the other groups, however this result can be interpreted as if students revert to thinking of such a force when an object is moving upwards freely in the air. Therefore, and despite the fact that students can explain the free falling by the existence of gravity, they could need to consider a cause for the upward and horizontal trajectory of the object. Even so, it is only a minority of group F who choose a force along the motion, even in this situation.

To look further at students' choices of a force along the motion, further analyses of selected groups and situations will be made. The analysis in Table 6.V omits groups D, F and G and situations (4) (i.e. sit. 3-2) and (5) (i.e. sit. 5-2), so that the cases which show most variation are left out, and retaining only Portuguese students, to limit cultural variations. With this selection, the variation of students' physics background is reduced but retains an interesting range, from pupils with no formal teaching in dynamics up to the end of secondary school.

(i_1) <u>Force along the motion</u>: Portuguese students up to the end of secondary school (groups A, B, C and E) and all selected situations except when a change in the direction of the motion is about to occur

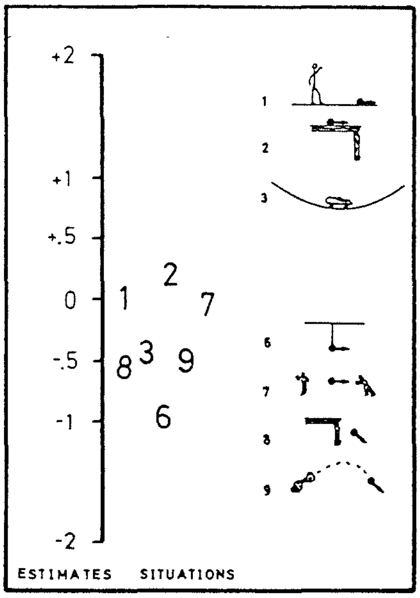
Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	64.98	27	<.0005			
GP	51.68	24	≃.001	13.30	3	≃.005
ST	28.52	21	≃.15-.1	36.46	6	<.0005
ST + GP	14.76	18	≃.7	50.22	9	<.0005

TABLE 6.V: Values yielded by the GLIM analysis with respect to students' choices of a force along the motion, for some groups and situations

Despite removing the more extreme groups and situations, the results can not still be regarded as essentially without variation (null model is a bad fit). The variations can not be well explained only by the effect of groups, and in fact the effect of group is quite small, though significant. The variations in the data can, however, be fairly well explained by differences in the situations alone (situation model is just a good fit, $p \simeq .15 - .1$). That is, the different groups considered here did not differ much in choosing a force along the motion, but their answers do depend, significantly, upon the situations.

The situation + group model is a very good fit ($p \simeq .7$) so that variations in the data are very well explained if one combines the group and situation effects.

Figs. 6.14 - IV and V show, respectively, the values of the estimates of effects found in the situation + group model for each situation and group, again showing that the differences are bigger for the situations than for the groups.



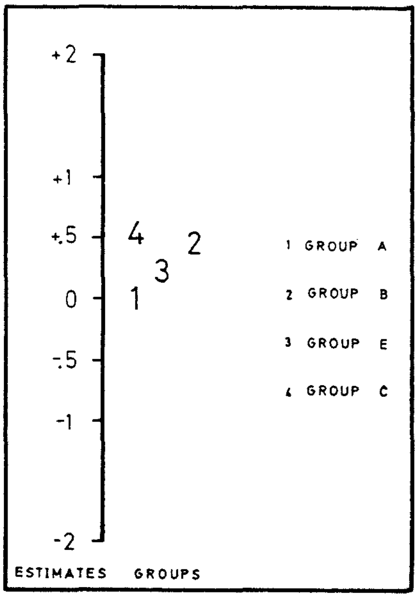


Fig. 6.14 – IV: Values of estimates, in each situation, for the ST + GP model, for the force along the motion

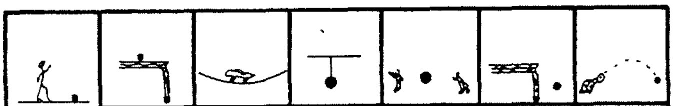
Fig. 6.14 – V: Values of estimates, in each group, for the ST + GP model, for the force along the motion

Fig. 6.14 – V shows that group (1) and (3), i.e. pupils with no formal teaching in dynamics and Arts university students gave very similar answers, as noted before. Indeed, the groups are all very similar. It is, then, clear that teaching, up to the end of secondary school, has not removed students' intuitive ideas that a force exists along the motion.

With respect to variations within situations, Fig. 6.14 – IV illustrates that situation (1), (2) and (7) are similar in more often producing a force along the motion. The differences between situations should be judged remembering that choices of a force along the motion are in all cases rather high (>50%), differences being relative to that percentage. Thus, those differences are relatively minor. Even so, one can advance possible explanations of the differences. I incline to think that the reasons may be of two kinds.

One reason, concerning situations (8) and (9), which correspond to the cases where objects are falling freely, is that students tend to choose a force along the motion less often when there is a 'natural' cause for the object to keep moving, that is gravity. It may be worth nothing, in support of this interpretation, that the residuals from the situation + group model (see Fig. 6.14 – VI) show a decrease in choices of force along the motion when there is a gravitational explanation of the motion, for just the groups who have learnt more physics, who may be expected to substitute gravity for force along the motion. However, the model is a good fit, so that perhaps such residuals ought not to be given any interpretation. It would be interesting to investigate in further studies whether teaching, rather than affecting the idea that a force is needed to keep motion, just teaches that gravity is **that cause** in some cases, namely when objects are falling freely. More generally this would look as if teaching which does not take into account students' previous ideas/beliefs, does not change them but just alter, in some cases, the way ideas are verbalized. This hypothesis has already been suggested in the literature, for example, by Viennot (1983) which suggests that students with more experience in physics just give more scientific names/justifications for their previous ideas.

The second reason, concerns situations (3) and (6), has been mentioned before, and is that a force is thought to be needed not only to keep motion along the same path but also to change the direction of the motion. Indeed situations (3) and (6) correspond to instants of the motion where a change in the direction of the motion is about to occur (see also previous discussion of sit. 3-2 and 5-2). If this is the case, these situations could have attracted choices of a force in the direction along the future motion, and so fewer along the motion. This explanation would be supported if it were the case that in these situations there are many choices of a force along the future motion, and if the result appears more frequently for the groups with less experience in physics. The residuals do in fact support the second point (see Fig. 6.14 - VI), though again it should be noticed that it may not be legitimate to give them any interpretation.



	1	2	3	6	7	8	9
A						+	
B			–			+	
E							
C			+			–	

Fig. 6.14 - VI: Extreme residuals found in the ST + GP model, for students' choices of a force along the motion

(ii) Downward vertical force (gravity): **All groups and selected situations**

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	1208.	60	$<.0005$			
				1162.69	6	$<.0005$
GP	45.31	54	$\simeq.7$			
				15.	8	$\simeq.05$
ST	1193.	52	$<.0005$			
				1183.35	14	$<.0005$
ST + GP	24.65	46	$\simeq.995$			

TABLE 6.VI: Values yielded by the GLIM analysis with respect to students' choices of a downward vertical force (gravity), for all groups and all selected situations

The figures in Table 6.VI indicate that there are systematic variations in students' choices of a force in the downward vertical direction (null model is a bad fit, $p<.0005$). The group model does, however, explain rather well these variations (group model is a very good fit, $p \simeq .7$), showing that groups with different physics background answered significantly differently in choosing a downward vertical force.

Although the change in G^2 on introducing the effect of situations is just significant, it seems best to regard the effects of situations as negligible, in view of the good fit of the model of group effects alone and the excessively good fit when situations are included. Thus students' ideas do not seem to be here contextualized.

The inspection of the values of group effects shows that some estimates are very large, mainly for groups with more experience in physics, i.e. groups D and F, and that the calculation had not converged after 10 cycles. This can be explained by the extreme variations of the frequencies of answers between the groups, which are rather low for group A and nearly unity for groups D and F. For this reason, the analysis will be repeated after removing groups D and F since the program can not model effects where the fraction of responses is zero or unity. Similarly as before, group G is also removed.

(ii$_1$) <u>Downward vertical force (gravity)</u>: **Portuguese students with physics experience up to the end of secondary school (groups A, B, C and E), in all selected situations**

Model	Scaled Deviance G^2	Degrees of Freedom df	p
Null	639.3	35	$<.0005$
GP	33.21	32	$\simeq .4$
ST	627.7	27	$<.0005$
ST + GP	17.09	24	$\simeq .850$

ΔG^2	Δdf	p
606.09	3	$<.0005$
11.6	8	$\simeq .15$
622.21	11	$<.0005$

TABLE 6.VII: Values yielded by the GLIM analysis with respect to students' choices of a downward vertical force (gravity), for some groups and all situations

Table 6.VII indicates that there are significant variations in the data, which are, as before, rather well explained by the group effect only (group model is a good fit, $p \simeq .4$). Differences between the situations are not significant (ΔG^2 not significant, $p \simeq .15$). These results confirm that students' ideas about gravity change, significantly, from when they enter physics classes, up to the end of secondary school. The differences between groups can be seen in Fig. 6.15, showing the values of the estimates, of each group, found for the group model.

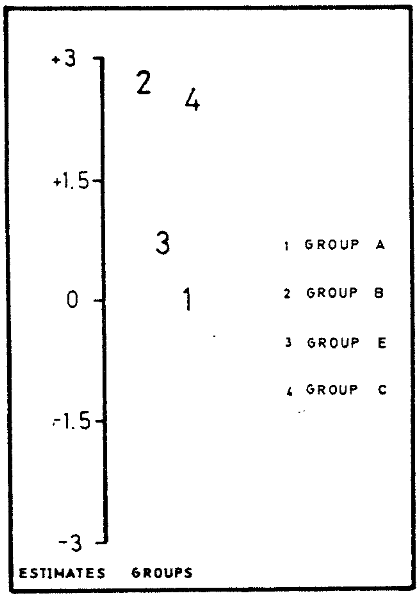


Fig. 6.15 - Values of estimates, for each group, in the GP model, for the downward vertical force (gravity)

The group effects fall into two pairs **(a)** pupils with no teaching in dynamics (group A) and Arts university students (group E) and **(b)** groups with some teaching in dynamics (groups B and C). The pairs are similar, with a large difference between pairs. As discussed in sub-section 6.2.1.2, it seems that as soon as teaching takes place students start to consider gravity much more frequently, but that no remarkable changes occur with a further increase in teaching (groups B to C).

As in previous analyses, Arts university students tend to answer similarly to pupils with no teaching in dynamics.

These results may be compared with those concerning students' notion of a force along the motion, in which differences between these groups were **not** large, and raise the question of what physics teaching actually changes in terms of students' conceptual systems about motions and their causes? Without pretending to give a simple answer to this complex problem, one may say that the results suggest that it does not change much, at least up to the end of secondary school.

Comparing these results with those found in previous studies of students' ideas of gravity (e.g. Watts, 1983), another interesting aspect seems to arise. Those studies pointed out the existence of a diversity of pupils' alternative frameworks about gravity, in particular, that pupils have intuitive ideas about gravity which seem to be rather strongly contextualized. The present results do not seem to fit such an interpretation. Having regard to the differences in the methodologies used in the different studies, one might suggest, that when students are not approached in a way which prompts answers in terms of gravity, they tend either not to consider such force often (before teaching) or to consider it (after teaching) and, in both cases, in a way which suggests that their notions are rather independent of the context of the situation.

(iii) Forces of support: All groups and selected situations

Model	Scaled Deviance G^2	Degrees of Freedom df	p
Null	748.0	46	$<.0005$
GP	121.4	40	$<.0005$
ST	618.7	40	$<.0005$
ST + GP	31.99	34	$\simeq .6$

ΔG^2	Δdf	p
626.6	6	$<.0005$
129.3	6	$<.0005$
716.01	12	$<.0005$

TABLE 6.VIII: Values yielded by the GLIM analysis with respect to students' choices of a force of support, for all groups and all selected situations

Table 6.VIII indicates that there are systematic variations in the data (null model is a bad fit, $p<.0005$) and that both groups and situations significantly affected, students' choices of a force of support. The differences due to the group effect are the larger (bigger decrease of G^2 when the group effect is added to the null model). Here, then, it seems that physics teaching affects, significantly, students' notion of forces of support and that this variable contributes more to variations in students' answers than the situation factor.

The situation + group model fits the data very well ($p \simeq .6$) indicating no need to consider interactions between group and situation (i.e. no dependence on situation of the group effect, or vice-versa).

Fig. 6.16 - I and II show, respectively, the values of the estimates of effects found for the situation + group model for each situation and group.

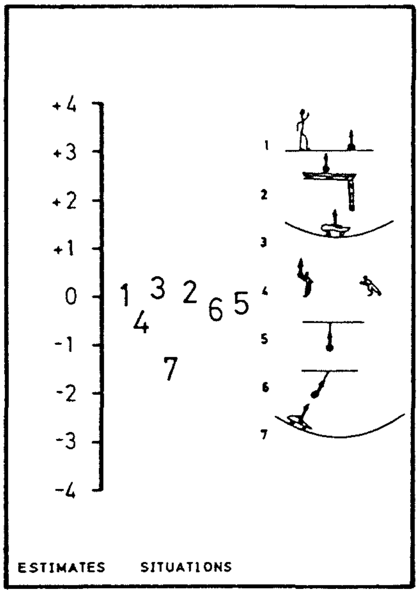


Fig. 6.16 – I: Values of estimates, in each situation, for the ST + GP model, for the force of support

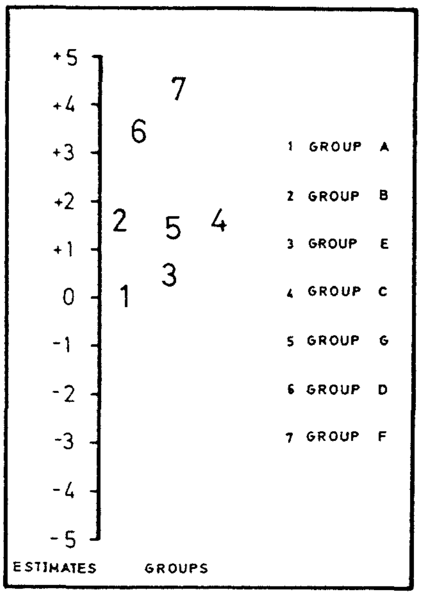
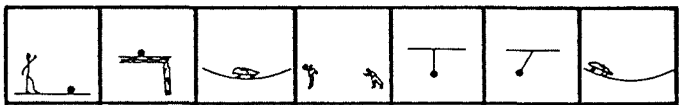


Fig. 6.16 – II: Values of estimates, in each group, for the ST + GP model, for the force of support

Fig. 6.16 – I indicates that the situation which differs most from the rest is situation (7), a car on a sloping surface. As mentioned in sub-section 6.2.1.3, a possible reason why support is chosen less often here is that students continue to consider a force of support in the upward vertical even though this is not the direction a physicist would choose. The other situations do not show large variations.

Fig. 6.16 – II shows that pupils with no teaching in dynamics and Arts university students chose a force of support less often than the groups with more experience in physics. It also indicates that groups with considerable experience in Physics, namely university physics students (groups D and F), chose such a force more often than students with less experience. These results do therefore suggest that the effect of teaching is real, although a substantial increase only occurs after a considerable amount of teaching. They also suggest that although the effect due to some experience in physics (i.e. group B) seemed to be considerable, it once again seems to fade with time, with Arts university students and pupils with no formal teaching again being similar.

A brief inspection of the residuals in the group only model (see Fig. 6.16 - III), confirms that situation 7 is the only one where large residuals were found. This suggests repeating the analysis omitting situation (7).



	1	2	3	4	5	6	7
A							
B		+	+				−
E	+		+				
C							−
G							
D						−	−
F						−	−

Fig. 6.16 - III: Extreme residuals found in the GP model, for students' choices of a force of support

(iii$_1$) <u>Forces of support:</u> All groups and situations except situation (7) (car on a sloping surface)

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	625.9	39	<.0005	582.9	6	<.0005
GP	42.9	33	≃.15	13.8	5	≃.025
ST	612.1	34	<.0005	601.7	11	<.0005
ST + GP	24.25	28	≃.7			

TABLE 6.IX: Values yielded by the GLIM analysis with respect to students' choices of a force of support, for all groups and situations except situation (7)

Table 6.IX shows that, after removing situation (7), the variations in the data are fairly well explained by the effect of groups only (group model is a reasonable fit, $p \simeq .15$). This suggests that students' choices of a force

of support depend, significantly, on students' physics background and that they depend at most only a little on the situations.

Fig. 6.16 - IV, showing the estimates of effects found for the group model, for each group, indicates how groups differ.

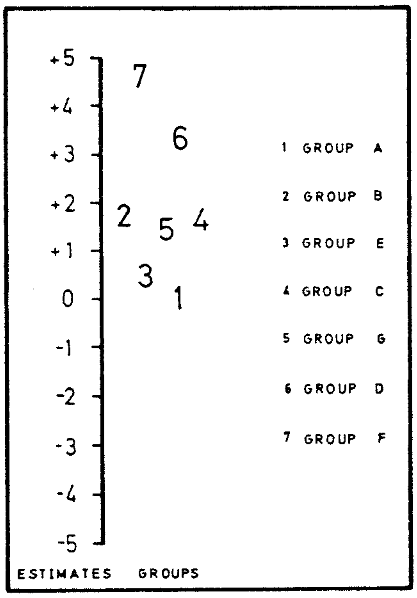


Fig. 6.16 - IV: Values of estimates, for each group, for the group model, for the force of support

In agreement with the discussion in sub-section 6.2.1.3, it can be seen that:

(a) an increase in physics teaching prompts more choices of forces of support, although a substantial increase only occurs with a considerable amount of teaching (group D and F);

(b) before physics teaching has taken place (group A), or when it has ceased for some years (group E), students do not consider such a force very often.

(iv) Forces of resistance: All groups and selected situations

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δ df	p
Null	557.8	61	<.0005	249.4	6	<.0005
GP	308.4	55	<.0005	155.6	8	<.0005
ST	402.2	53	<.0005	420.1	14	<.0005
ST + GP	137.3	47	<.0005			

TABLE 6.X: Values yielded by the GLIM analysis with respect to students' choices of a force of resistance, for all groups and all selected situations

From Table 6.X one can see that none of the models studied fit the data well indicating the presence of interactions between groups and situations, which themselves also have significant effects.

As previously, and remembering that effects indicated by a poorly fitting model are unreliable, the analysis will be looked at in terms of the values of the estimates of effects found with the model which fits best (situation + + group), to get some idea of the variations in the data (see Fig. 6.17 – I and II).

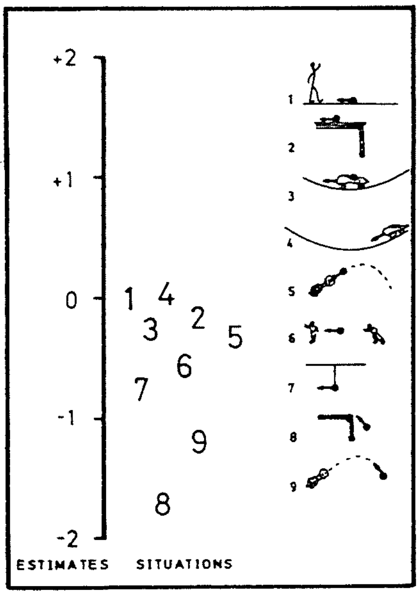


Fig. 6.17 – I: Values of estimates, in each situation, for the ST + GP model, for the force of resistance

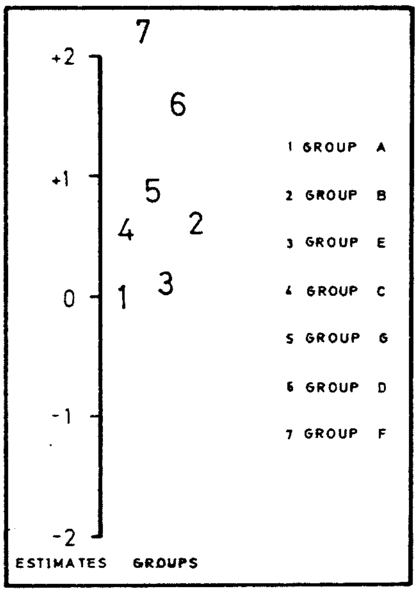


Fig. 6.17 – II: Values of estimates, in each group, for the ST + GP model, for the force of resistance

Fig. 6.17 – I, showing the values of the estimates for each situation, indicates that despite the considerable differences between situations, there are some which seemed to have attracted similar answers. In all the situations where forces of resistance are due to solid friction (i.e., situation (1) to (4)), students frequently chose a force of resistance, and situations where forces of resistance are due to the air, are those for which students chose such force less often (i.e. situation (7) to (9)). There are two exceptions: situation (5), a cannon ball on its upward motion, and situation (6), a ball after being thrown by a man, both of which attracted frequent responses of a force of resistance.

Fig. 6.17 – II, showing the values of the estimates for each group, indicates that, generally, groups with more teaching chose forces of resistance more often. However, a substantial increase only occurs after a considerable amount of teaching, i.e. for physics university students (groups (6) and (7)). Arts university students gave, again, similar answers as pupils of group A, by not often considering forces of resistance at all.

To examine the significant interactions, the residuals found for the situation + group model will be examined. Fig. 6.17 – III shows the extreme residuals.

	1	2	3	4	5	6	7	8	9
A	–			–	+			+	
B									
E							+		
C									
G									
D	+	+					–	–	
F							–		

Fig. 6.17 – III: Extreme residuals found in the ST + GP model, for students' choices of a force of resistance

Fig. 6.17 – III indicates that large residuals are located essentially only in the most extreme groups (groups A, D and F). Group A considers resistance even less than usual in the case of a kicked ball, but more often than usual for a ball falling from a table or rising in the air. Groups D or F, by contrast, attribute solid friction more often than they usually attribute resis-

tance, but choose resistance less often than usual for a suspended ball or one falling from a table. This might suggest that the group with little experience of physics is rather unsure about resistance, and that the groups with most experience find some conflict between their practical and their scientific knowledge. The data, however, is hardly enough to make any such speculations trustworthy.

Because the interactions are associated with 'extreme' groups, it seems worth repeating the analysis with these groups removed. This will be done independently for cases of solid and air friction.

(iv$_1$) **<u>Forces of resistance due to solid friction</u>: Portuguese students with physics experience up to the end of secondary school (groups A, B, C and E)**

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	56.4	15	$<.0005$			
				47.9	3	$<.0005$
GP	8.5	12	$\simeq.7$			
				3.8	3	$\simeq.3$
ST	52.6	12	$<.0005$			
				51.9	6	$<.0005$
ST + GP	4.5	9	$\simeq.850$			

TABLE 6.XI: Values yielded by the GLIM analysis with respect to students' choices of a force of resistance (solid friction), for some groups and situations

For solid friction (Table 6.XI) variations in the data are now well explained by the effect of groups only, (group model is a very good fit, $p \simeq .7$) with differences between situations not being significant ($p \simeq .3$). There is thus no longer any interaction between groups and situations. This suggests that students' physics experience, even up to the end of secondary school, is a deciding factor in their choices of a force of resistance due to solid friction, and that in this case, their ideas are rather independent of the context.

Fig. 6.17 - IV, showing the estimates found for the group model, for each group, indicates that the biggest variations occur between students

with some formal teaching in dynamics (groups B and C) and pupils with no teaching and Arts university students (groups A and E), the former choosing a force of resistance more often. As the analysis done in sub-section 6.2.1.4 indicated that groups A and E chose a force of resistance rarely, these results suggest that the notion of such force is a product of teaching. However, again the results seem to suggest that this acquired notion fades with time.

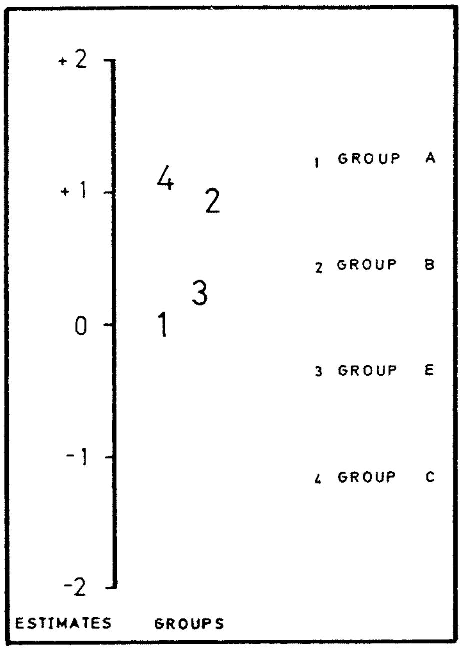


Fig. 6.17 - IV: Values of estimates, in each group, for the GP model, for the force of resistance (solid friction)

(iv$_2$) <u>Forces of resistance due to the air</u>: Portuguese students with physics experience up to the end of secondary school (groups A, B, C and E)

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	51.9	19	<.0005	3.47	3	≃.2
GP	48.5	16	<.0005	30.6	4	<.0005
ST	21.4	15	≃.15	34.2	7	≃.0005
ST + GP	17.8	12	≃.15			

TABLE 6.XII: Values yielded by the GLIM analysis with respect to students' choices of a force of resistance (air resistance), for some groups and situations

Taking now forces of air resistance, we find a quite different pattern. Table 6.XII indicates that variation in the data due to the effect of groups are now not significant ($p \simeq .2$) but instead that those variations are well explained by the effect of situations only (situation model is a reasonable fit, $p \simeq .15$). The situation + group model is also a good fit ($p \simeq .15$) but, obviously, does not add much towards explaining the variations. From this, it appears that physics experience up to the end of secondary school does not much affect ideas about the existence of air resistance, but that these ideas seem to be dependent primarily on context.

Fig. 6.17 - V and VI show the estimates of effects found for the situation + group model, for each situation and group respectively.

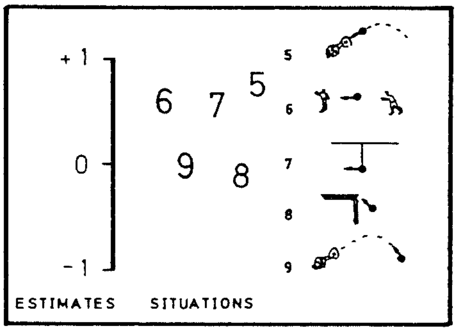


Fig. 6.17 - V: Values of estimates, in each situation, for the ST + GP model, for the force of resistance (air resistance)

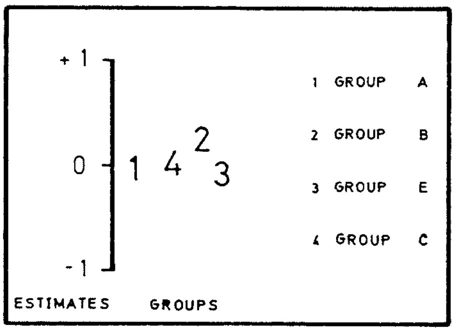


Fig. 6.17 - VI: Values of estimates, in each group, for the ST + GP model, for the force of resistance (air resistance)

Fig. 6.17 - VI just illustrates that groups do not vary appreciably. As was seen in sub-section 6.2.1.4, one can say that only a minority chose such a force. Fig. 6.17 - V indicates that the biggest situational difference occurred between situations where objects are falling freely (i.e. situations (8) and (9)) and where (usually) there is or is about to be a decrease in the speed of the object (i.e. situations (5) and (7)), the former being those in which students chose a force of resistance less often. It may seem that some students, though not many, feel a need for a resistance to motion when the speed actually decreases (situation (6), the ball after being thrown by a man, is however an exception to this interpretation).

It is interesting that choices of a force of resistance, at least up to the end of secondary school, due to solid friction and to air resistance differ so markedly in pattern. That is, the analysis suggests that the notion of solid friction is acquired substantially with teaching and it is not contextualized, whilst the notion of air resistance does not seem to vary with teaching and it is contextualized.

One possible interpretation for those differences is that teaching does in fact treat more frequently situations where there is solid friction, and perhaps more often ignores air resistance. Indeed, following the hypothesis that solid friction is an acquired notion one would expect it to be rather non-contextualized. If, however physics teaching up to the end of secondary school does refer to air resistance forces, an alternative possibility could be that solid friction forces are better understood by students as their effects are more visible in the natural physical world than are those of air resistance.

(v) Impulsive forces: All groups and selected situations

Model	Scaled Deviance G^2	Degrees of Freedom df	p	ΔG^2	Δdf	p
Null	22.88	13	$\simeq .05$	16.3	6	$\simeq .01$
GP	6.54	7	$\simeq .5$	2.97	1	$\simeq .1$
ST	19.91	12	$\simeq .075$	19.3	7	$\simeq .01$
ST + GP	3.6	6	$\simeq .7$			

TABLE 6.XIII: Values yielded by the GLIM analysis with respect to students' choices of an impulsive force, for all groups and all selected situations

Table 6.XIII shows that the null model almost begins to fit ($p \simeq .05$) indicating that there is rather little variation between groups and situations. Correspondingly that there are only barely significant differences due to the effect of groups ($p \simeq .01$) and no significant differences due to the situation factor ($p \simeq .1$). As might be expected, the situation + group model is a very

good fit ($p \simeq .7$) without any evidence for interactions between groups and situations. This confirms what was suggested in sub-section 6.2.1.5, that the majority of students of all groups more or less agreed in choosing an impulsive force in the situations considered.

This result is particularly interesting as this is the only case in which, despite the large differences in students' physics background, students' ideas do not differ considerably. And this is, most probably, because pupils' prior ideas are in agreement with physics teaching.

CHAPTER 7

ANALYSIS OF NAMES GIVEN TO FORCES

7.1 – Introduction

As mentioned previously, the questionnaire not only asked students to choose directions where forces might exist but also to name them. Alternatively, the students could answer by putting an **N** in the direction chosen, in case they did not know how to name the force.

This additional data will be used to investigate further the kinds of forces students think exist. It will also be used to check the previous analysis of non-verbal responses in terms of choices of directions of forces. It will be particularly important to look at cases where the names given conflict with the directions chosen.

Because students could answer by naming a force or by putting an **N**, there will be evidence about whether students can name the forces chosen and, in particular, whether students were more sure about the existence of forces in certain directions than about the nature of those forces.

The analysis falls into two parts. In the first, section 7.2, a general classification of students' answers according to the types of names (including no name) given to the forces is set up and the general results found for the different groups and situations are presented. In the second, section 7.3, a more detailed analysis is given of the answers concerning particular forces and forces in particular directions, distinguishing more intuitive and more acquired ideas. It will be also focused on situations which appear to be particularly interesting, in the light of previous analysis.

7.2 – Preliminary Analysis of the Names for the Forces

7.2.1 Main questions addressed and nature of the data: some problematic aspects

Before the presentation and justification of the scheme set up for the general classification of names given to forces, a preliminary discussion is needed of some problematic aspects concerning the nature of the data collected and the questions addressed in the analysis. These problems are not specific to this study, but are general and are often referred to in other analysis of qualitative data.

The two main questions addressed in the analysis, at this stage, are **[Q1] to what extent students are able to name forces?** and **[Q2] what meaning does a name have in terms of the concept of force involved?** The first presents few problems, but the second is more difficult. The main difficulty is one of the level of interpretation it is proper to make, which would ideally be not merely a simple description of the names students use to designate forces but rather an understanding of the concepts behind the names given. This is problematic, in view of the nature of the data collected and the limited information contained in it.

Broadly speaking, the data consists of simple words naming forces. These may either be terms also used in a physics context (for example, 'impulsive force' or 'gravity'), or names given to other physical entities (for example, 'energy', 'speed'). In the first case it is not always true that their use agrees with the physicist's point of view. For example, students often name forces which do not exist in a physics context, but use scientific names for them. Also, the same student does not always seem to name the forces consistently. For example, the name 'force exerted by the man on the ball' was given, by the same student, for the impulsive force when a man is kicking a ball (in sit. 1-1) and for the force along the motion when a ball is moving by itself (in sit. 1-2). This example suggests that one can fail to tap differences in the concept of force involved if one sticks just to the name given to the forces without trying to interpret its meaning in the context of the situation. Such interpretation may reduce the risk one is taking in classifying the answers, given the limited information contained in the data collected, i.e. usually only a word-name.

This problem does not necessarily occur to the same extent with all groups of students. For those with more experience in physics the risk of inferring from the data would probably be smaller, at least for the forces whose existence appears to be more a result of formal teaching.

7.2.2 Criteria for the analysis

The following main criteria have been followed in the analysis:

(i) students' answers will first be analysed in terms of whether or not they contain information about the kind of force students chose. Thus **N** answers will be classified differently from those where a name was given;

(ii) when a name is given to the force, the interpretation of its meaning is made in the context of the situation (see the discussion above).

The two next criteria help to support the decisions to be made in interpreting the names given by students to the forces:

(ii_1) in order to interpret the concept behind a name given by any student of a group in any situation, one would search for similar names given by the same student in other situations so one can bring more evidence about what the student means by the word used;

(ii_2) the name given by any student to a particular force, in any situation, will be compared with the names given to the same force and situation by other students of the same group.

Thus, for instance, the force along the motion when a ball is moving by itself (in sit. 1-2) is named 'impulsive force' by some students of group A and 'force exerted by the man' by others. This last name more clearly suggests that the student is thinking of an 'internal force' which has been given to the ball when the man kicked it. The comparison between the two names given will help to support the decision about classifying a name, such as 'impulsive force', in that context as an 'internal force' despite the fact that this name is given, in a physics context, for an interactive force.

7.2.3 Network used in the analysis

The network in Figure 7.1 was developed and used to describe names given to forces. The network was developed from the data, but also from insights backed by previous research (e.g. Ogborn, 1985, Viennot, 1983, Watts, 1983).

The two basic categories of the network are **NON-NAMED FORCE/ /CAUSE** and **NAMED FORCE/CAUSE.**

NON-NAMED FORCE/CAUSE refers to answers in which no information is given about the kind of force/cause students chose. They correspond either to a **Nil** category where, essentially, nothing is said about the kind of students' choice, or to **Replication of the event**, where students just re-describe the event itself. [An example of answers to be included in the last category would be, 'the ball is rolling', 'the ball falls down']. The N and Name Says Nothing sub-categories refer, respectively, to answers in which students put an N and wrote a name which does not say anything about the force/cause chosen [for example, 'exerted force', 'horizontal force', 'small force'].

NAMED FORCE/CAUSE refers to answers in which some information is given about the kind of force/cause. Its sub-category, **Internal to Object**, refers to cases where the name given and the context where it is used suggests that the student is thinking of a force/cause internal to the object. The words used by students here were mainly names of forces which are usually used in a physics context but are at odds with the physicist's perspective, or names of other physical entities which are in someway associated with the object itself.

Internal to Object is itself divided into three further sub-categories.

The Force/Cause Referred to Past Condition sub-category can be thought of a 'force' which has been previously exerted on the object by some other agent and which the object has kept/uses, for instance, to keep itself moving. An example would be the name 'impulsive force' or 'force exerted by the man on the ball' when used to name the force along the motion when a ball is moving by itself after it was kicked by a man [i.e. sit. 1-2].

The Function of State sub-category can be though of a 'force' which is being generated by the state of motion of an object, either by its motion [Speed/Motion] or by the energy it possesses [Energy]. An example would be the name 'force of the speed' or 'force of the falling' when given to the force along the motion.

GROUP: ____________

SITUATION: ____________

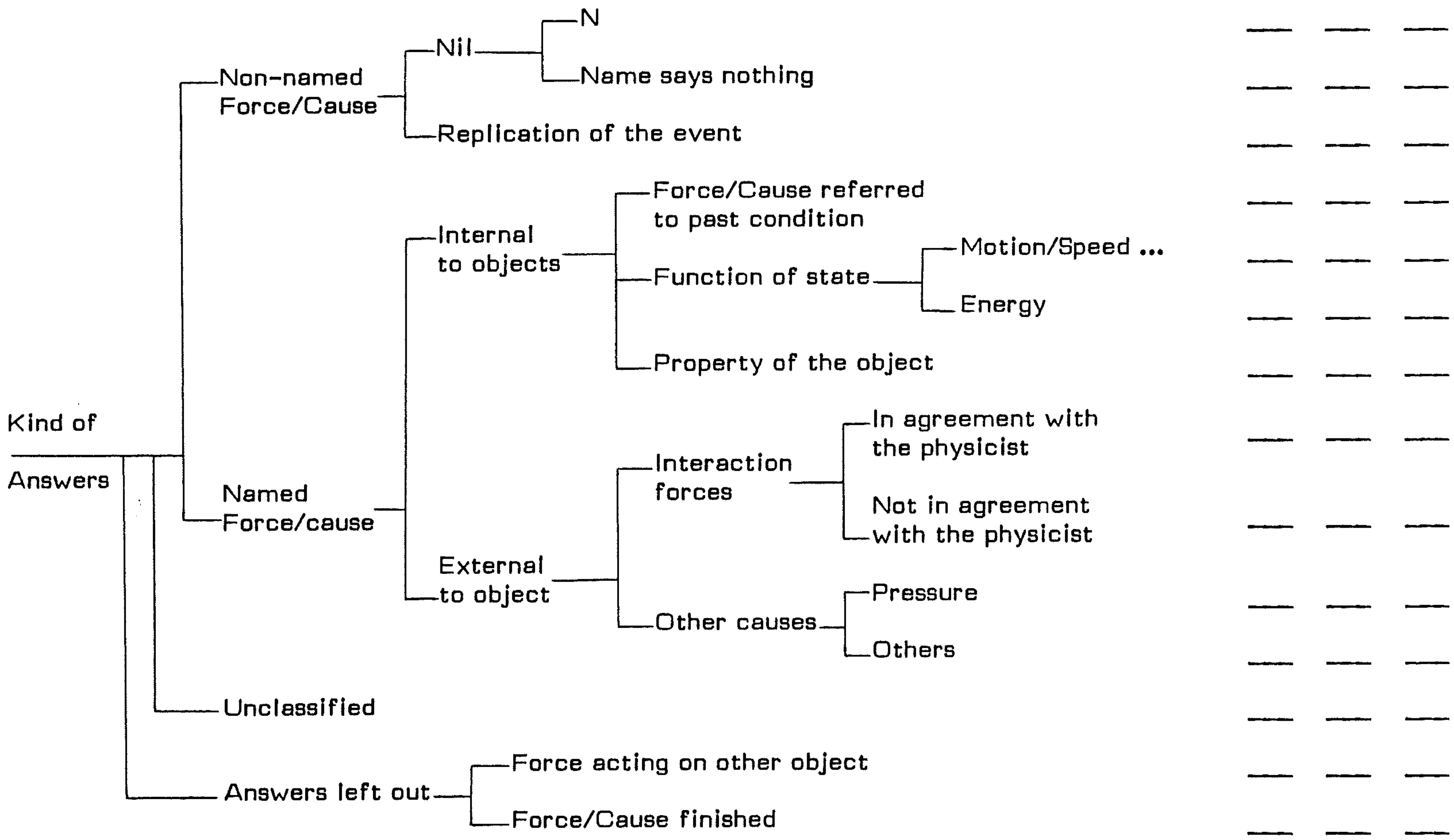


Fig. 7.1 - Network used in the analysis of names given to forces

The Property of Object sub-category can be thought of as a 'force' generated by the object. An example would be 'the force of the ball' or 'the balance of the ball' when these names are given to the force along the motion.

One could argue against the validity of these last distinctions on the grounds of the limited information in the data. Nevertheless, I have decided to make such distinction as I consider it important for the differentiation of students' conceptualizations. Notice that the notions involved in those definitions were mainly taken from a theory which attemps to formulate students' conceptualizations of motion (Ogborn, 1985). The frequency of responses which correspond to these sub-categories will not, however, be used at this stage of the analysis but only, and then mainly in a speculative way, in section 7.3.

The other main category of named forces, **External to Object,** refers to cases where the name given and the context where it is used suggests that the student is thinking of a force/cause external to the object. The words used by students are mainly names of interaction forces in situations where these forces exist from the physicist's point of view, and names of other physical entities which are usually associated with an external entity to the object. As the questionnaire asks about forces, it was decided to distinguish these two kind of responses in the two following sub-categories:

Interaction Forces correspond to answers where the names given suggest that the students' concepts are close to the physicist's notion of force. This is then further subdivided into those which are In Agreement With the Physicist, and those which are Not in Agreement With the Physicist (usually because they are in the wrong direction). This last sub-category also includes names which suggest that the particular concept of force the student was thinking of does not have the same meaning as that attributed by the physicist to the same word-concept, but still suggests a concept close to the concept of interaction force. An example would be an answer of the kind 'gravity, the force exerted by the air'.

Still **External to Object,** the category Other Causes refers to answers which suggest that students are thinking of a cause which although not usually considered as a force, is still external to the object, of which Pressure is important enough to distinguish, the rest being grouped under Others.

Apart from the categories defined above, the network also includes an **UNCLASSIFIED** category which corresponds to answers whose meaning it is not possible for the analyst to understand as, for example, 'force of progression'. Such replies were generally given only once, which makes it very difficult to interpret what they mean.

Reference is also made in the network to answers which were left out of the analysis, either because the name suggests that the force is acting on another object besides the one the questionnaire actually asks about, and where the name suggests that the force/cause does not exist anymore.

The analysis is made, separately, for each group and situation, fitting the data into the categories defined before. The results to be discussed next will, however, be presented in comparison for all groups and situations.

7.2.4 Overall results

The results obtained are presented in detail in Appendix III, where the numbers of answers found for each category of the network are displayed, for each group and situation. Appendix III also contains an analysis of the problematic results namely those concerning the **Unclassified** cases and the **Answers left out** of the analysis. It is shown there that they are relatively infrequent. Had they been more frequent, the validity of the network would have been called in question.

Summaries of those results concerning, mainly, the questions addressed in sub-section 7.2.1, will here be presented in two parts. In the first, the analysis looks at whether or not students named the forces chosen. In the second, the analysis aims to bring further information about the notions behind the forces/causes chosen by students.

In the following discussion, the results will be summarized graphically using 'schematic plots' (Erickson and Nosanchuk, 1977). Frequencies are shown as boxes extending between the upper and lower quartiles, with a line across the box at the median (Md). The length of a box, which is then equal to the difference between the upper and lower quartile (dq, the midspread), is the measure used here for the spread of the data. The median shows the central tendency of the data. Far Outliers are marked above or below the box with a circle, representing frequencies at least 3 x dq above the upper quartile or below the lower quartile.

(i) Can students name forces?

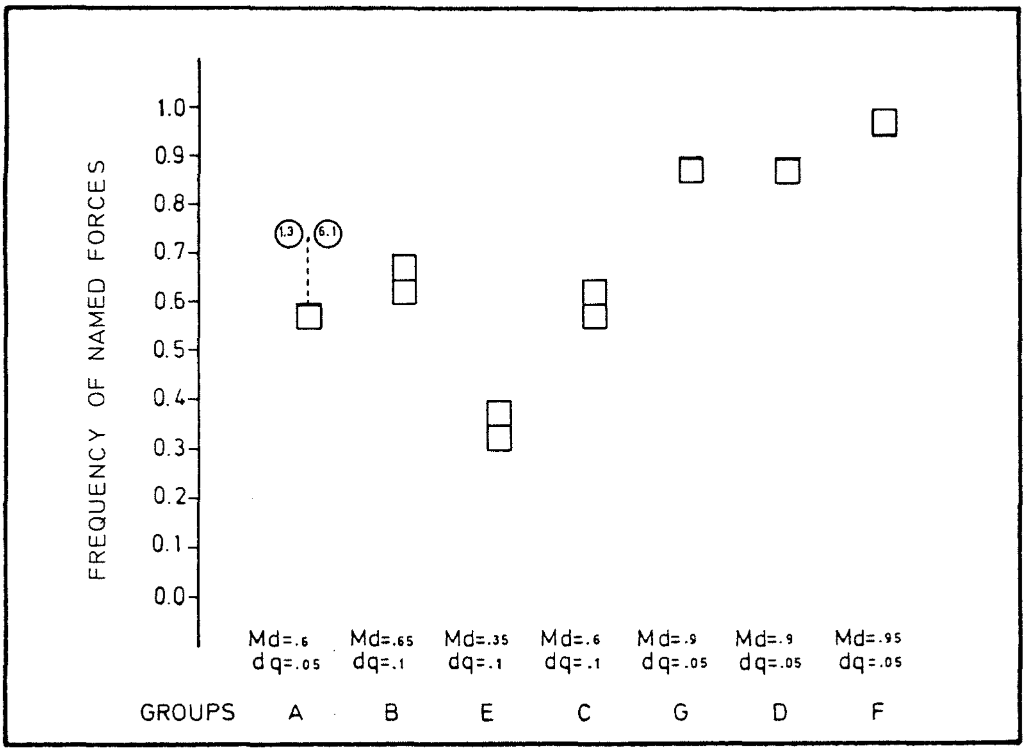


Fig. 7.2 - Schematic plots of frequencies of Named Forces, for each group, in all situations

Fig. 7.2, showing the schematic plots of the frequencies of named forces, in all situations, for each group of students, indicates that:

(a) generally, the tendency, for all groups, is for more than 50% of the forces chosen to be named (except that Arts university students named forces less often (about 35%)). The frequencies tend to rise as years of teaching increases, to 90% and more for groups D and F from 60% for group A;

(b) variations across situations are small. An exception occurs with group A, in sit. 1-3, a ball at rest after being kicked, and 6-1, a man throwing a ball, where many more choices were named.

Thus, one may say that students, generally, did tend to name forces, and that teaching is associated with a further substantial increase in naming forces.

(ii) Are named forces/causes always external to the object?

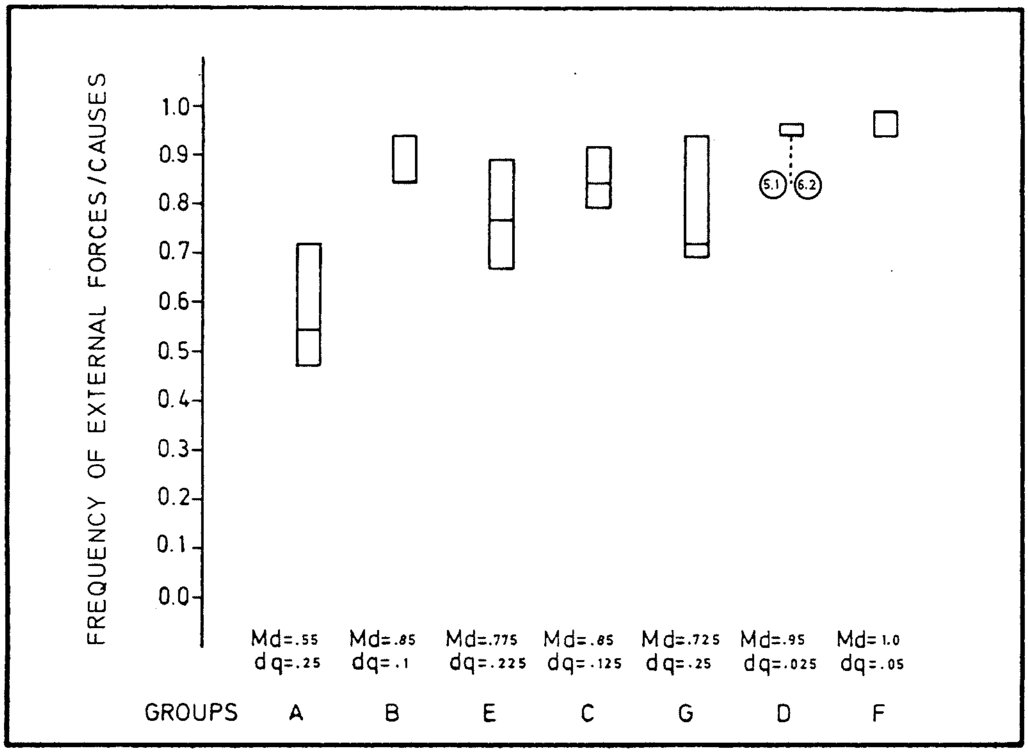


Fig. 7.3 - Schematic plots of frequencies of External Forces/Causes, for each group in all situations

Fig. 7.3 shows the schematic plots of the frequencies of external named forces/causes. The most remarkable aspect of the results concerns the large variations across situations as compared with the relatively small variations between most of the groups. As may be seen, external named forces were quite often chosen (more than 70%) except only for pupils with no formal teaching in dynamics (Md = .55). For group E, the results may not be particularly reliable as most of their choices were not named (see the previous discussion).

The variations across situations are particularly large (about 20%), for groups with no formal teaching (group A) and groups who had finished their studies in physics for some years (groups E and G). These variations are reduced for groups with some teaching (groups B and C) but a substantial reduction only occurs with university physics students (groups D and F).

These results suggest that, except for group A and possibly E, most named forces/causes are external to the object. Teaching seems to prompt more of such answers although its effect is not particularly big, occurring mainly when students are involved in the process of learning physics at school. However, large variations seem to have occurred between situations, mostly for groups with smaller experience in physics. The existence of these variations points out the need to look more carefully at the kinds of forces students chose in the different situations. Since 'force along the motion' is possibly the main kind of non-external cause, situations involving moving objects (mainly where gravity may not explain the motion) are expected to be those in which external causes are less often chosen. This hypothesis will be considered in the next section.

(ii.1) <u>Are interactive forces always in agreement with the physicist?</u>

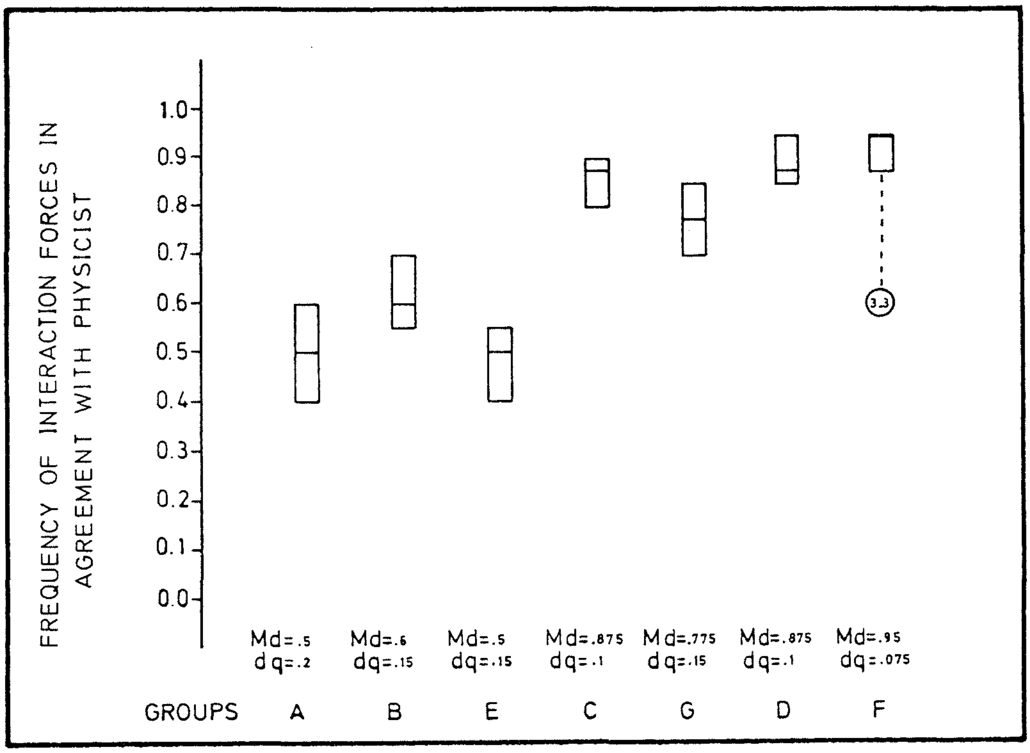


Fig. 7.4 - Schematic plots of frequencies of Interaction Forces in Agreement With the Physicist, for each group in all situations

Fig. 7.4, showing the schematic plots of the frequencies of interaction forces in agreement with the physicist, in all situations, for each group, indicates that:

(a) generally more than half of the interaction forces considered, by all groups, are in agreement with the physicist. It also shows that an increase in the frequency of those answers occurs with teaching. Particularly interesting is that, for the first time, there is a clear improvement in the answers of group C, compared with group B;

(b) variations across situations tend to be larger for groups with less experience in physics (groups A, B, E and G). An extreme case occurs only with group F, for sit. 3-3, a ball falling freely from a table. Suppose where students' choices of air resistance were often given in the upward vertical direction and not in the direction opposite to motion (see discussion given in Chapter 6, sub-section 6.2.1.4).

7.3 - Analysis of Names Given to Particular Forces and to Forces in Particular Directions

The analysis here investigates further the nature of the forces students named, leading to an attempt to identify students' notions about each force considered, by inspecting each student's set of answers in all situations.

The forces to be discussed are divided into two groups; forces likely to be acquired through teaching, and forces with a more intuitive basis.

7.3.1 Forces acquired by teaching

7.3.1.1 Gravity

(i1) Are downward vertical forces usually named as expected?

For the downward vertical direction one would expect students to choose a gravitational force, giving it a name such as gravity/weight/attractive force of the earth. Fig. 7.5 indicates the frequency of such named choices. The frequencies are shown relative to the total number of choices of a force in that direction. Situations which are unusually frequent or infrequent are indicated.

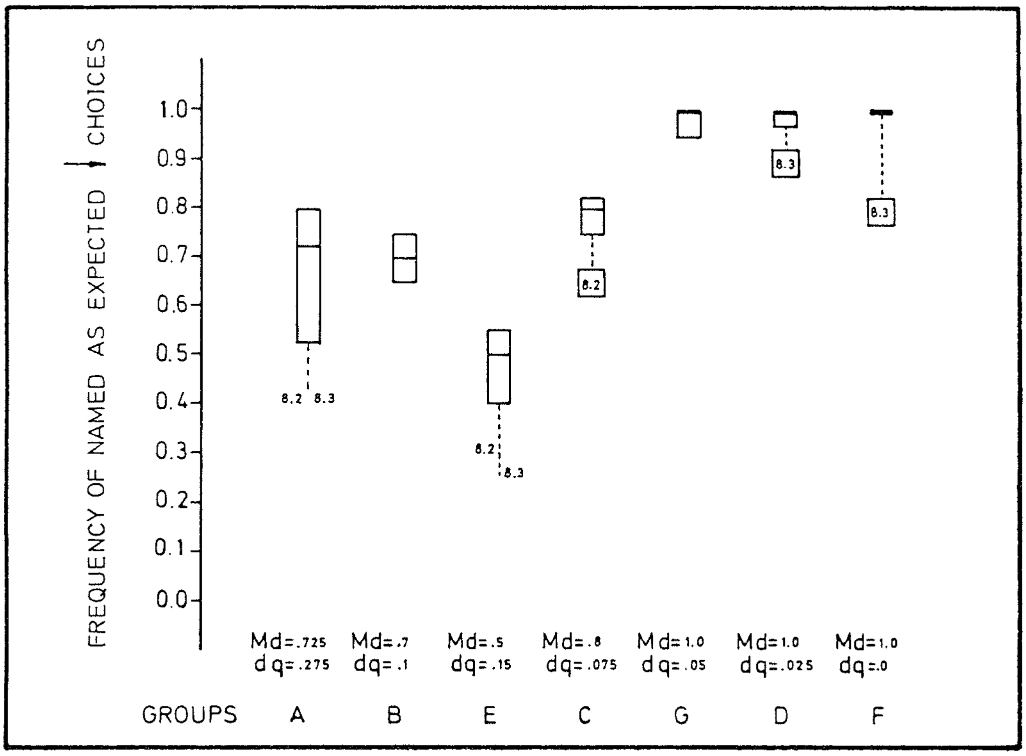


Fig. 7.5 - Schematic plots of frequencies of named-as-expected downward vertical forces, for each group, in all situations

Generally, the results indicate that the majority of students, who chose a downward vertical force, named this force as expected (Md $\geqslant$ .7) and that they did so with small variations across situations (dq $\leqslant$ .1). The frequency of choices, increases, and the variation with situations decreases, with amount of teaching. Arts students, however, only did so about half the time and group A did so much less consistently in all situations. The exceptional sits. 8-2 and 8-3 seem to be cases of confusion with other forces, not a neglect of gravity.

(i2) Do non-named forces and other kinds of forces act vertically and downwards?

From the evidence given before one can already conclude that, for almost all groups and situations, only a minority of choices were non-named and/or named differently from expected. Fig. 7.6 and 7.7 showing, respectively, the frequencies of non-named and other kinds of forces which students chose acting vertically and downwards, reinforces that conclusion.

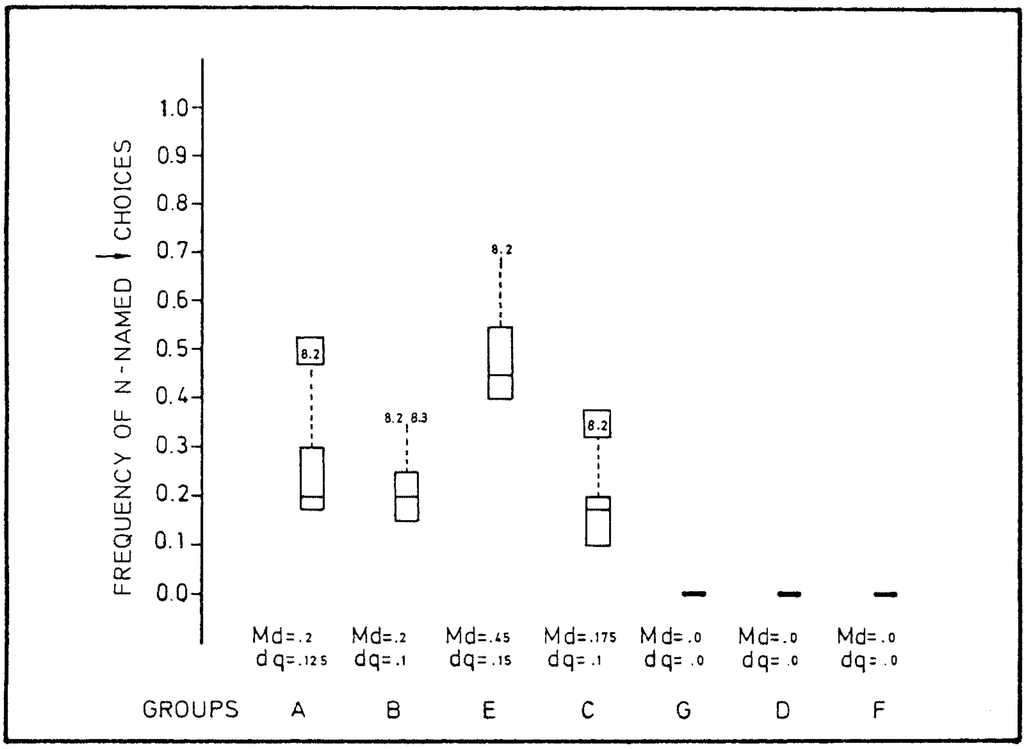


Fig. 7.6 - Schematic plots of frequencies of non-named downward vertical forces, for each group, in all situations

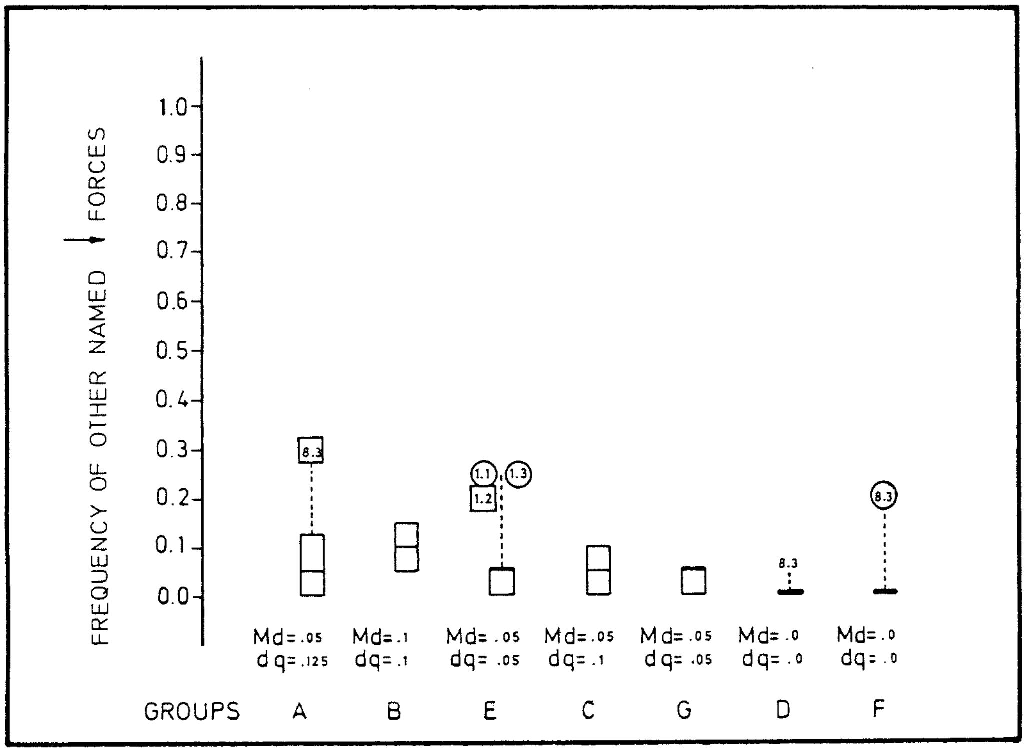


Fig. 7.7 - Schematic plots of frequencies of other named forces acting vertically and downwards, for each group, in all situations

Fig. 7.6 shows that most students were rather sure about the nature of the force chosen, the exception being Arts university students, who seem to be more sure about the existence of a force than about the name to be given to it.

For all groups with little or no experience in physics (groups A to C), an extreme case occurs in sit. 8-2, where more choices were non-named. This suggests that students considered a force, other than gravity, which students think to exist, but that they are not sure about its nature, possibly, as was mentioned previously, a force along the motion.

Fig. 7.7 indicates that, essentially, no other forces were considered in the direction under study, apart from gravity. An extreme case occurs, for some groups, with respect to sit. 8-3. In it other forces were also considered, by some students, namely the 'force of the water' (group A) and the 'water resistance' (group D and F).

(ii) Does gravity exist in other directions than the one expected?

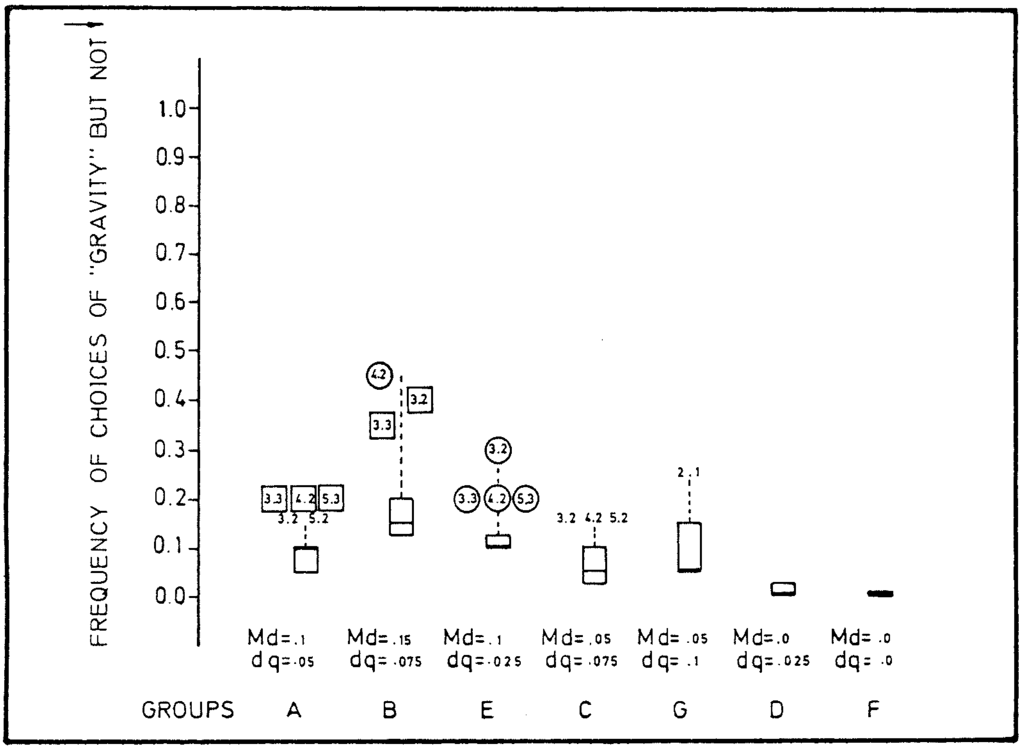


Fig. 7.8 - Schematic plots of frequencies of a named force 'gravity' acting in other directions than expected, for each group, in all situations

Fig. 7.8 showing the frequencies of students' choices of forces named gravity/weight/attractive force, in directions other than vertically downwards, indicates that:

(a) generally, for all groups and in almost all of the situations, the number of such answers is rather small (Md $\leqslant .1$), and zero for groups with most experience in physics (groups D and F);

(b) for groups with little or no experience in physics, there are, however, some extreme cases where such a force was considered more often. All of these situations correspond to cases where objects are falling, or are about to fall, freely in the air. As Fig. 7.9 shows, the other directions where 'gravity' was mostly chosen was the direction along the present or future motion.

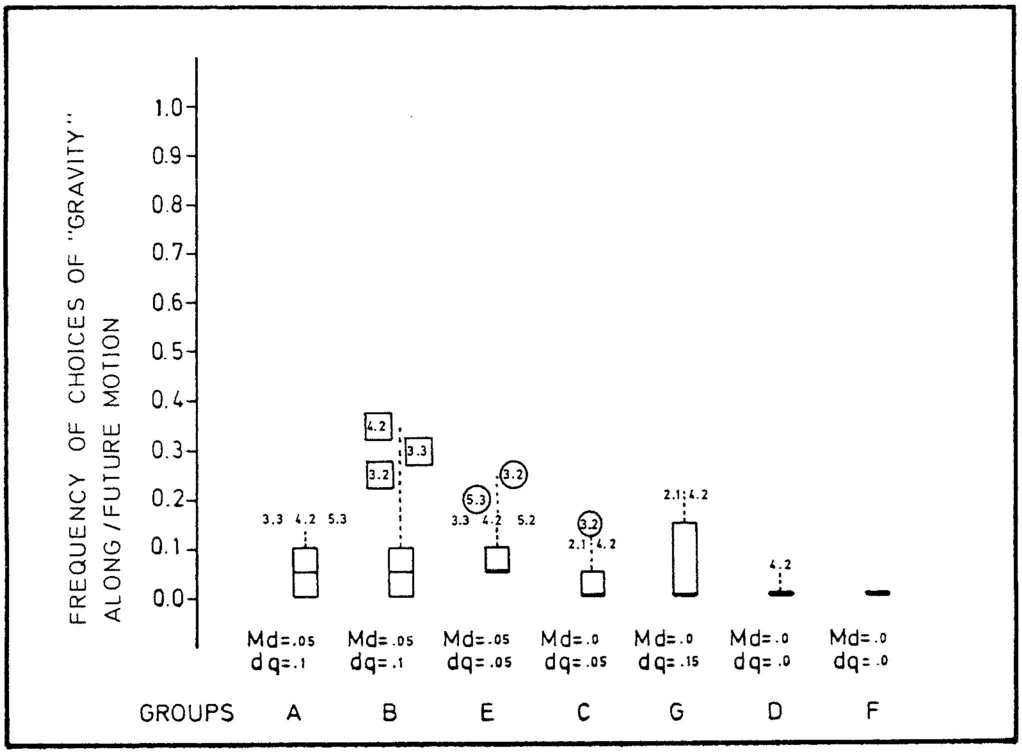


Fig. 7.9 – Schematic plots of frequencies of choices of 'gravity' in the direction along the motion and/or along the future motion, for each group, in the situations where objects are moving

In conclusion, one can say that although gravity existed mainly in the direction expected, and without much variation across situations, it also existed, for some students, in situations where objects are falling freely or about to fall, where it usually operates in the direction along the motion or along the future motion.

(iii) Students' conceptions about gravity

From the analysis of each individual student's set of answers with respect to her/his choices of a force named gravity/weight/attractive force, in all situations of the questionnaire, I was able to define the following categories of replies, which covered the majority of replies.

(iii.1) No need for Gravity. This category includes students who never considered such a force. Fig. 7.10 shows, for each group, the percentage of these answers.

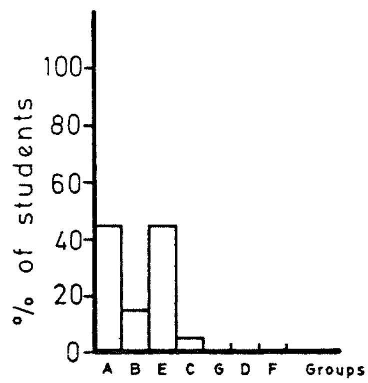


Fig. 7.10 – Percentage of students, of each group, included in the **'No need for Gravity'** category

The results indicate that a considerable number of pupils with no formal teaching in dynamics and Arts university students, answered the questionnaire without needing to consider gravity at all. As soon as teaching takes place (group B) this number decreases, being zero for groups with most experience in physics. It appears then that gravity is primarily absent, for an appreciable number of pupils, being substantially added to the system only with teaching. However (as has been pointed out several times previously) the effect of that teaching seems to fade with time.

(iii.2) **'Gravity' is Contextualized: only needed to explain motion, when objects are falling freely or about to fall.** This category includes students who named a force gravity/weight/attractive force, but only in rare situations, mainly when objects are falling or about to fall. Usually this force acts along the motion. Fig. 7.11 shows, for each group, the percentage of these students.

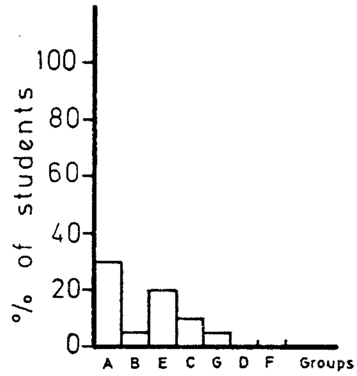


Fig. 7.11 - Percentage of students, of each group, included in the **"Gravity' is Contextualized (...)'** category

The results indicate that this use of 'gravity' is mostly held by pupils with no formal teaching in dynamics (30%) and Arts university students (20%). With teaching, this percentage decreases, being zero for groups with most experience in physics. Notice that similar results have been found by previous researchers (e.g. Watts, 1982).

(iii.3) **'Gravity' is Rarely Contextualized but has a different meaning from the Scientific View.** This category includes two distinct types of answers, but having in common the fact that 'gravity' is considered in all or almost all of the situations. These are, **(1)** answers suggesting that **'Gravity' is not 'Weight',** in that students usually considered two different forces, in the same situation, naming them 'gravity' and 'weight', **(2)** answers suggesting that students have a **Mixed notion of 'Gravity',** as being in most of the situations a force acting towards the centre of the earth but which operates also along the motion, mainly when objects are falling or about to fall.

Fig. 7.12 shows, for each group, the percentage of students who gave both kinds of answers.

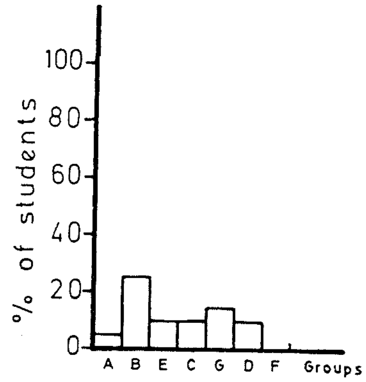


Fig. 7.12 - Percentage of students, of each group, included in the **"Gravity' is Rarely Contextualized but has a different meaning from the Scientific View'** category

The results indicate that, although not very frequently, these answers occurred more often for groups with some experience in physics. The small number of cases found and the fact that these answers were not found for youngest pupils do not, however, mean that all the other students associate gravity and weight, as this study can not be seen as exhaustive in this matter. Actually, students' differentiation of gravity and weight has been pointed out by other researchers (e.g. Stead and Osborne, 1979, Watts, 1982) as being a frequently held framework.

In conclusion one can say that even when students with little experience in physics seemed to have acquired the notion that gravity is a rather universal force, some tend to mix it with their prior notions.

(iii.4) **Gravity in Agreement with (or close to) the Scientific View.** This category includes answers in which gravity/weight/attractive force was chosen in all situations acting vertically and downwards. It also includes some answers in which either gravity was missing in only few of the situations, or in which gravity not only acted vertically and downwards but also in nearby directions. These answers were considered to be, in essence, close to the scientific view in that, the former were mainly considered by students with more experience in physics and there seemed to be little consistency among the situations where gravity was missing.

With respect to the second, they seem to suggest only that students did not yet always associate a force with a unique direction. Indeed, these last answers occurred mainly for groups with less experience in physics.

Fig. 7.13 shows, for each group, the percentage of students who gave both kinds of answers.

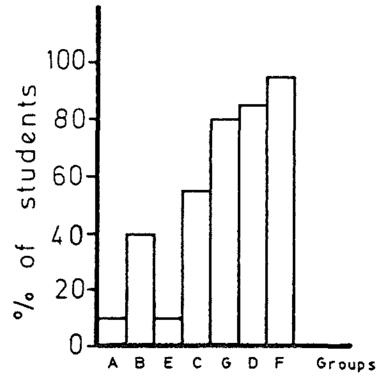


Fig. 7.13 - Percentage of students, of each group, included in the **'Gravity in Agreement with (or close to) the Scientific View'** category

The results indicate that the number of these answers is rather small (10%) for pupils with no experience in dynamics (group A) and Arts univerity students (group E), but it increases (to 40%), considerably, as soon as teaching takes place (group B), continuing to increase with teaching.

7.3.1.2 Forces of Support

The process of choosing criteria for including forces chosen as being forces of support, differs from that used before with respect to 'gravity'. The existence of 'gravity' was not, in principle, restricted to any situation and, therefore, any choice of that 'force' could be counted, whether or not it was also chosen in any other situation. Greater care is needed for 'support' because, such forces should be associated with an actual support, so that in looking for forces of support it is important to select choices which suggest the presence of a force associated with a real support and which did not exist when there was not a support. Thus even when a student named a 'Reaction' force when objects are being supported, if this force also existed when objects were not in fact supported, the answer is not included as being a force of support. Such cases were not, however, very frequent, existing only for groups with physics experience.

The results to be described next concern all the situations where objects are being supported. There is one exception (sit. 8-1, a man jumping from the springboard of a swimming pool). This situation will be treated separately because of the ambiguity about the direction in which the 'Reaction' should act (upward and vertically, or upward and to the right) and because both directions could have been chosen to represent a different force, i.e. the impulsive force (see discussion in Chapter 6, sub-section 6.2.1.5).

(ii) Are forces acting in the direction of forces of support usually named as expected?

For the forces acting in the direction of the forces of support one would expect students to give them names such as Reaction/Force exerted by the support (e.g. ground, table, man's hand) and Tension, for sit. 7. Figure 7.14 indicates the frequency of such named forces, if they only act when objects are being supported. The frequencies are shown relative to the total number of choices of a force in the direction of the force of support (the notation is the same as in the figures of the previous section).

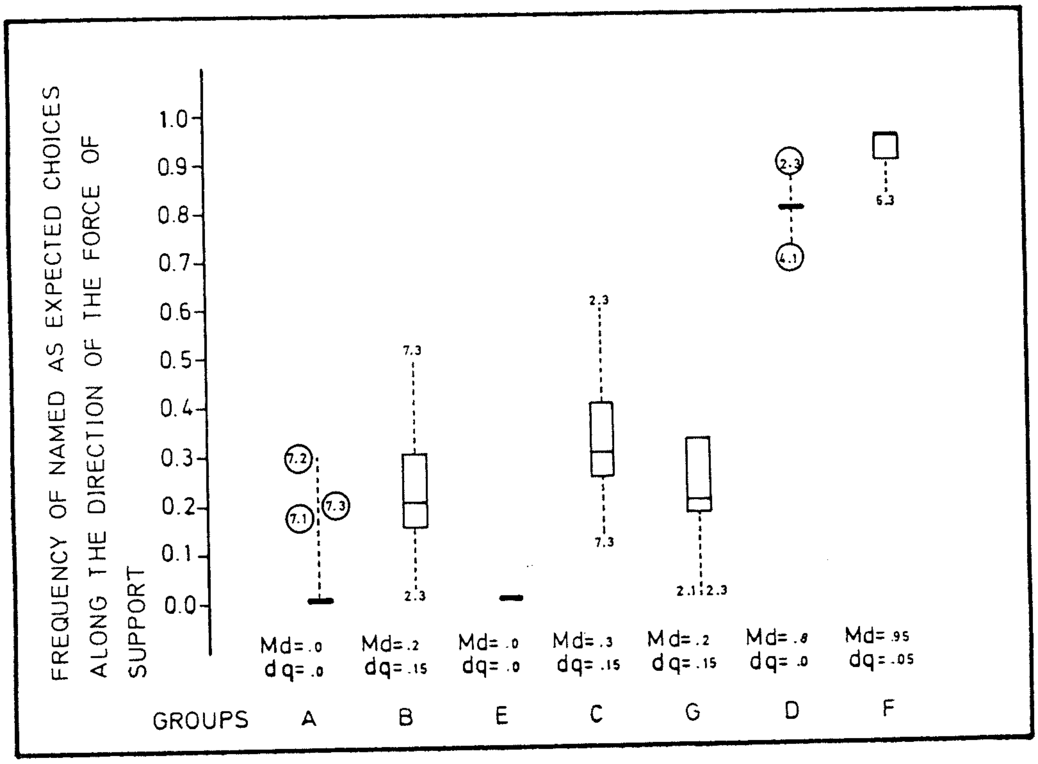


Fig. 7.14 - Schematic plots of frequencies of named-as-expected forces of support, for each group, in all situations considered

Generally, the results indicate that only groups with most experience in physics named the majority of their choices as expected (Md $\geqslant$ 0.8). Other groups only named a minority of the forces chosen as expected; in the case of groups with no or no recent teaching in dynamics (groups A and E) the frequency is essentially zero. There is possibly a slight increase in the frequencies of these answers with some teaching (group B and C).

The results do not indicate large variations across situations (dq $\leqslant$ 0.15), although there are a few extreme cases, mainly sit. 7-3 (a ball hanging from a string at an angle from the vertical) and 2-1 and 2-3 (a car on a sloping surface). The frequencies for these are sometimes high, and sometimes low. The variations may be due to the percentages being taken from rather few cases (see Chapter 6, sub-section 6.2.1.3).

(i.2) Do non-named forces and other kinds of forces act in the direction of the forces of support?

From the foregoing, it is already clear that for most groups the majority of choices were non-named or were named differently from expected. Figures 7.15 and 7.16 showing, respectively, the frequencies of non-named and other kinds of forces which students chose acting in the direction of the forces of support, illustrate this outcome.

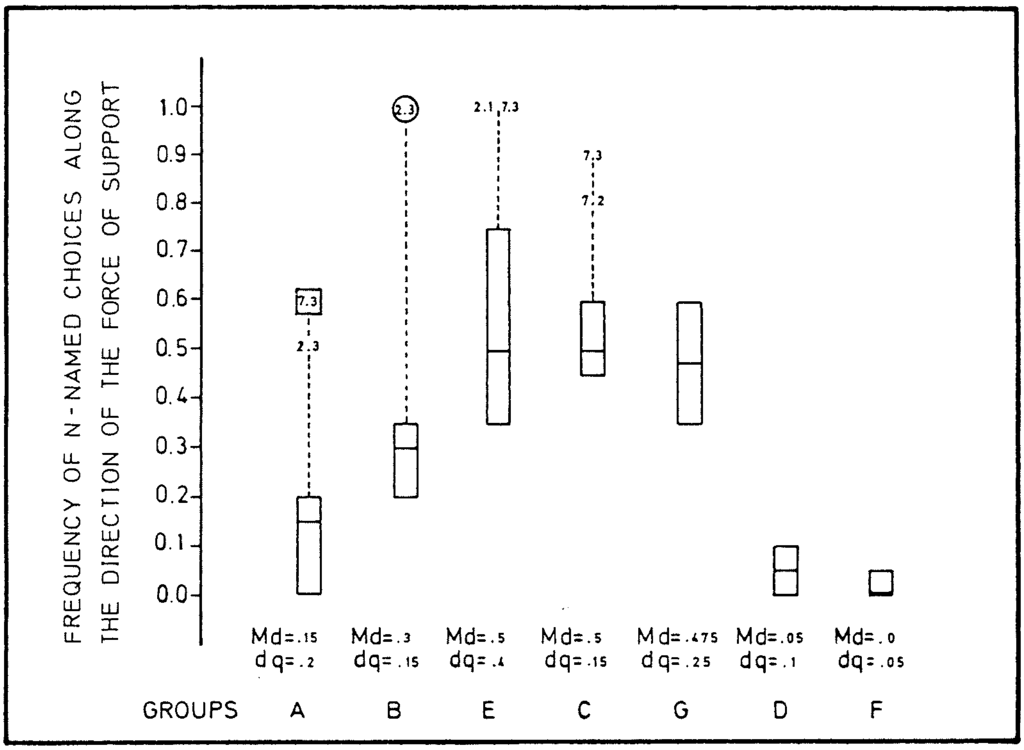


Fig. 7.15 - Schematic plots of frequencies of non-named forces in the direction of the forces of support, for each group, in all situations considered

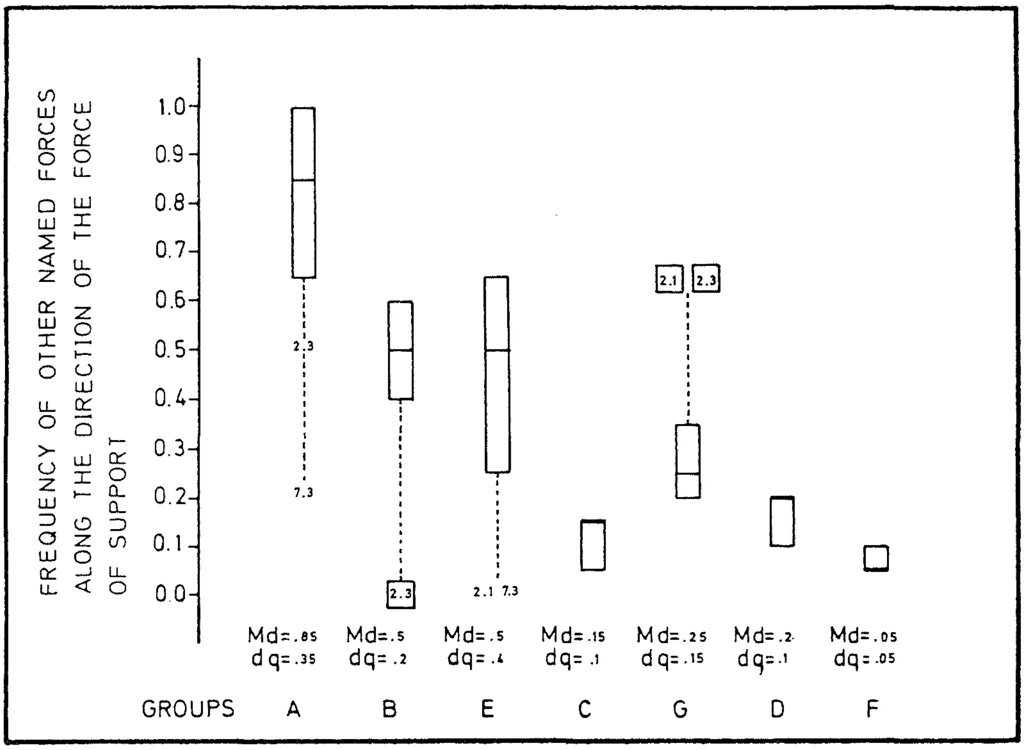


Fig. 7.16 - Schematic plots of frequencies of other named forces acting in the direction of the forces of support, for each group, in all situations considered

Figure 7.15 indicates that non-named forces are more frequent for groups with little (i.e. groups B and C) or no recent experience in physics (i.e. groups E and G).

Figure 7.16, showing frequency of choices of other named forces clarifies the results of Figure 7.15. Group A rather freely give other names to forces of support, and so rather fewer responses with no name. Groups with some more experience of physics, while not giving forces of support much more often (see Fig. 7.14), give fewer other name responses and more non-name responses, than group A. It seems that teaching has not clarified the notion very much although inhibiting responses with **unscientific names.**

Apart from the unusual cases mentioned before, the variations of choices of non-named forces with situations are not large, (dq $\leqslant$ 0.2) except for group E and perhaps group G.

For choices of other-names for forces, the variation with situations is somewhat larger, except for groups with considerable experience of physics. The forces mostly chosen by pupils of group A and Arts university students are related to the air, namely, 'air pressure' and 'force of the air'. Students of group B tend to consider a 'force exerted by the earth'.

In conclusion, and in agreement with the discussion given in Chapter 6, sub-section 6.2.1.3, one can say that the minority of pupils of group A and Arts university students who chose a force in the direction of the force of support (i.e. about 10%, in almost all situations) were thinking of other forces, namely forces associated with the air. Although the percentage of these choices increases with teaching (to about 40%, in almost all situations, at the secondary level, i.e. groups B and C), students' choices do not seem to be very often in agreement with what they have been taught. Thus, students of group B continue to consider, frequently, other forces, while students of group C mainly avoid naming these forces, suggesting that the nature of the forces was not fully understood. Only with a considerable amount of teaching, i.e. at the university physics level, does the percentage of these choices increase to about 80% (for group D) and more (for group F), and students' answers seem to be in agreement with the physicist's view. For almost all groups, unusual answers existed, namely those referring to situations where forces of support do not act vertically and upwards.

(ii) Do named 'forces of support' exist in other directions then the one expected?

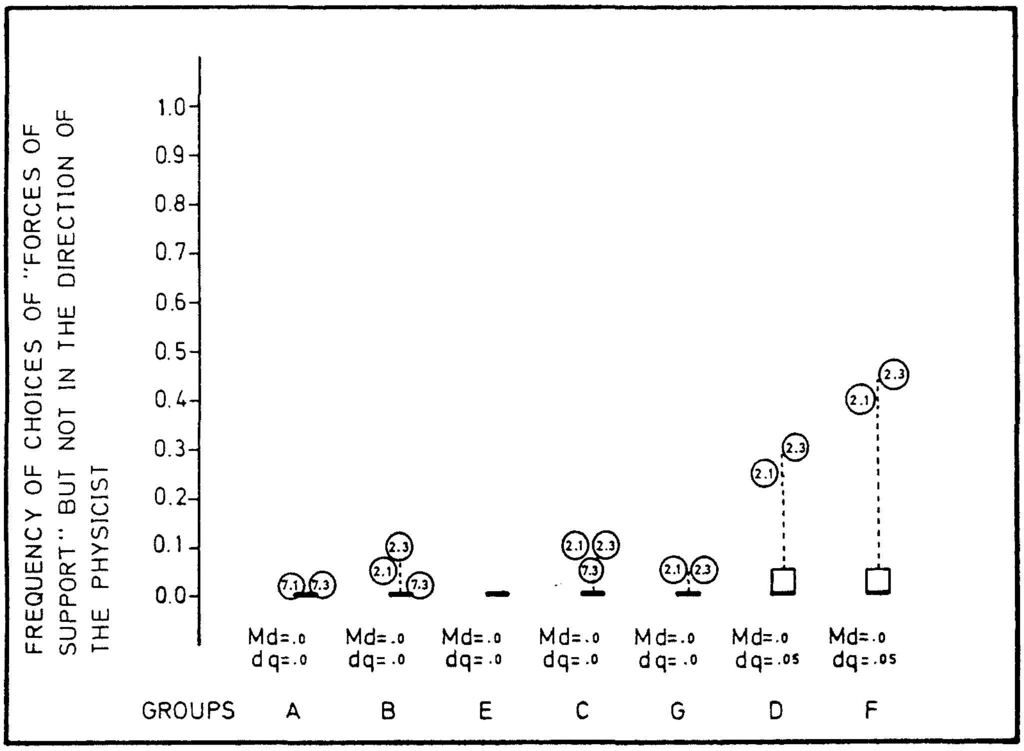


Fig. 7.17 - Schematic plots of frequencies of named 'forces of support' acting in other directions than expected, for each group, in all situations considered

Fig. 7.17 showing the frequencies of students' choices of 'forces of support' in other directions than the one expected, indicates that:

(a) for all groups, and in almost all situations, the percentage of such answers is very low or zero;

(b) for all groups, excepted group E, there are, however, some cases where a named 'force of support' was considered in other directions. They correspond to the situations where forces of support do not act vertically and upward. Table 7.I, shows that the direction where such 'forces of support' was mostly vertically upwards (see Chapter 6, sub-section 6.2.1.3). Perhaps forces of Reaction are thought of a counter-gravitational forces.

	Percentage of 'F. of Support' ↑ when they act at an angle to the ↑ direction		
Group	2.1	2.3	7.3
A	-	-	2%
B	5%	10%	2%
E	-	-	-
C	10%	10%	5%
G	5%	5%	
D	25%	30%	-
F	40%	45%	-

TABLE 7.I: Percentage of students choosing 'forces of support' in the vertical and upward direction, in the situations where they act at an angle to this direction, for each group

(iii) Students' conceptions about forces of support

An analysis of individual answers suggested the following categories of replies, about support, which cover the majority of replies:

(iii.1) No Need for Forces of Support. This category includes students who never considered such a force. In most cases this was because no force was chosen associated with the support; in a few cases this was because although students named 'forces of support' they also chose them in situations where there was not only physical support. Figure 7.18 shows, for each group, the percentage of this category of answers.

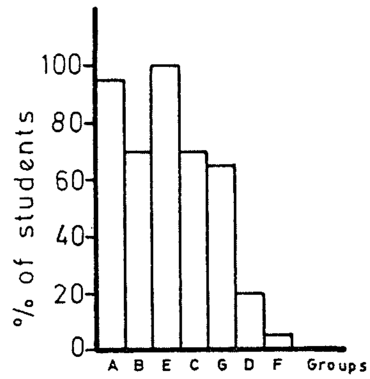


Fig. 7.18 – Percentage of students, of each group, included in the **'No Need for Forces of Support'** category

This data shows that the majority of students up to the end of secondary school and those with no recent teaching in physics (i.e. groups E and G) did not consider forces of support at all, the percentage increasing only a little with teaching, for the first few years. The need for forces of support is only substantially increased for university physics students (i.e. groups D and F).

(iii.2) Forces of Support are Contextualized. This category includes students who chose forces of support depending on the kind of support. The questionnaire presented three different kinds of support, i.e. 'solid' (e.g. the ground, a ball) a man's hand and a string. Figure 7.19 shows, for each group, the percentage of students who chose such forces only associated with particular kind (or kinds) of support(s).

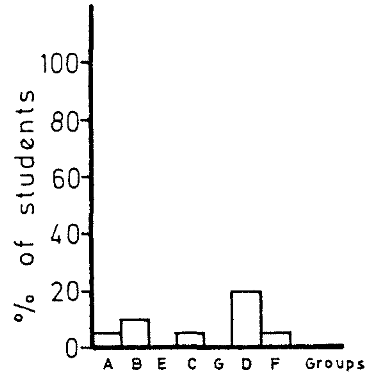


Fig. 7.19 - Percentage of students, of each group, included in the **'Forces of Support are Contextualized'** category

The percentage of such answers is rather small for all groups, suggesting that forces of support are not, generally, contextualized. However, if one compares these percentages with the total percentage of students with little or no teaching, who chose forces of support, one sees that students with little or no teaching tend to do it on a more contextualized basis than do students with more teaching. For example, all pupils of group A who chose forces of support, did it only in some situations (hanging on a string).

(iii.3) **'Forces of Support' are Rarely contextualized but continue to act vertically and upwards even when this does not agree with the physicist's view.** This category includes answers in which students chose 'forces of support' in all or almost all of the situations considered but acting, mainly, vertically upwards even in the situations where they act, from the physicist's point of view, at an angle to that direction, namely in situations 2-1 and 2-3 (a car on a sloping surface). A possibility is that 'forces of support' are needed to balance gravity which, therefore, would imply that they should act, always, in the opposite direction. Thus, these cases of replies were treated separately.

Figure 7.20 shows, for each group, the percentage of students who gave these answers.

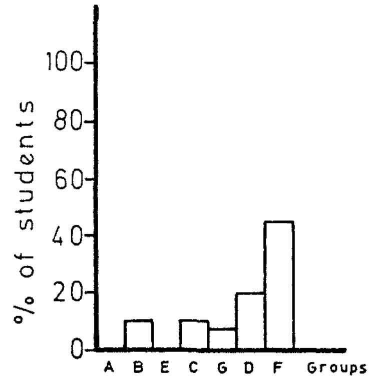


Fig. 7.20 - Percentage of students, of each group, included in the "**Forces of Support' are Rarely Contextualized [...]'** category

The results indicate that, apart from groups A and E who, in general, did not choose forces of support, some students of all the other groups gave these answers. The percentage is notably high for Physics trainee teachers of group F. Notice, also, that although only 10% of students with little experience in physics (i.e. groups B and C) gave such answers, this percentage corresponds to about one third of the total number of students who chose 'forces of support'.

These results do, therefore, suggest that this framework is fairly likely to be found among students who have experience in physics.

(iii.4) Forces of Support in Agreement with (or close to) the Scientific View.

This category includes answers in which forces of support were chosen in all situations where objects are being supported, acting always at right angles to the surface. It also includes some answers in which forces of support were missing in only a few of the situations.

Fig. 7.21 shows, for each group, the percentage of students who gave both kinds of answers.

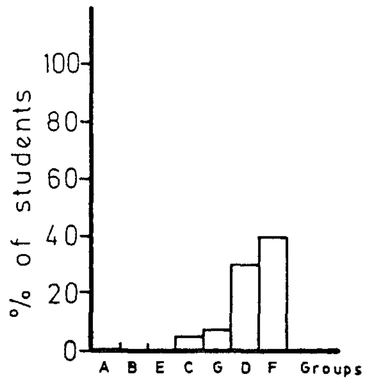


Fig. 7.21 – Percentage of students, of each group, included in the **'Forces of Support in Agreement with (or close to) the Scientific View'** category

The results indicate that, only after some years of formal teaching in physics, do students start to give such answers, and even then, it is not even a majority who do so.

(iv) Sit. 8–1: a man jumping from the springboard of a swimming pool

Given the ambiguity involved in this situation, the analysis is less detailed. Table 7.II shows, for each group, the percentage of choices implying 'support' in the vertical and vertical and to the right direction.

Group / Direction	↑	↗
A	-	-
B	5%	-
E	-	-
C	5%	-
D	35%	20%
F	35%	20%

TABLE 7.II: Percentage of students considering forces of support acting vertically and upwards or upwards to the right, in sit. 8–1, for each group

Generally, the figures in the table indicate that the tendency for students to choose forces of support, in both directions, is similar to that found in the other situations. Thus, students with no or no recent physics teaching did not consider forces of support, only a minority of students with some teaching chose them, the percentage of these answers being only substantially increased for university physics students. However, for all groups choosing forces of support, the percentage of these answers is smaller than before, perhaps because students considered only the instantaneous action of the support and, therefore, thought of it as an impulsive force. Table 7.III, which shows the percentage of students who usually considered forces of support in all the other situations, but not here (taking it instead to be an impulsive force), gives some support to this view.

Group	Percentage of students choosing an impulsive force instead of a force of support acting ↑ or ↗
A	-
B	5%
E	-
C	10%
D	15%
F	20%

TABLE 7.III: Percentage of students considering an impulsive force instead of a force of support in sit. 8-1, for each group

7.3.1.3 Forces of Resistance

The definition given for forces of resistance (see Chapter 6, sub-section 6.2.1.4) was that of forces opposite to the motion, which tend to reduce the velocity of the moving object. For this reason only answers suggesting forces of this nature were counted as forces of resistance, leaving out other answers which, although they may have been named 'frictional forces', suggested different meanings for these forces. Such cases were relatively frequent, mainly for groups with some experience in physics, and will be treated separately in 'Other uses of 'frictional' forces'.

From the evidence shown in Chapter 6, sub-section 6.2.1.4 and 6.2.2, about the differences in students' answers with respect to forces of resistance due to solid and air friction, they will be discussed first independently, and then in comparison. Results concerning forces of resistance due to water will be also discussed separately.

7.3.1.3.1 Forces of Resistance due to solid friction

(i.1) Are forces acting in the direction of forces of resistance usually named as expected?

For the direction opposite to motion, in all situations of the questionnaire showing objects moving on solid surfaces, one would expect students to choose a force of resistance, naming it friction. Figure 7.22 indicates the frequency of forces named as expected, relative to the total number of choices of a force in the direction of the force of resistance.

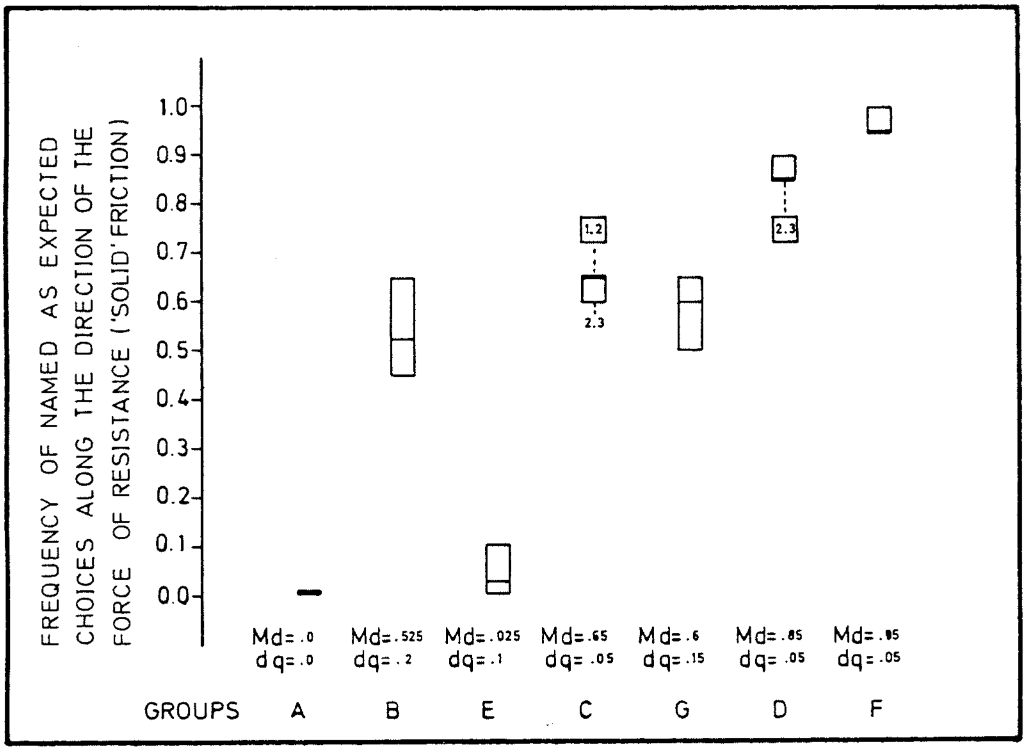


Fig. 7.22 - Schematic plots of frequencies of named-as-expected forces in the direction opposite to motion, for each group, in all situations where objects are moving on solid surfaces

The majority of students with formal physics teaching, who chose a force in the direction under study, named it as expected (Md > 0.5). The frequency of such answers increases with amount of teaching, mainly at the university physics level, where more than 80% of students' choices were named 'friction'. Pupils with no formal teaching in dynamics and Arts university students rarely, if ever, named their choices as expected. The results also indicate that, for all groups, variations with situations were small ($dq \leqslant 0.2$) and that only few extreme cases occurred.

These results, therefore, suggest that the students with physics experience who chose a force in the direction opposite to motion, were mainly thinking of a resistance force due to solid friction, while pupils with no experience in dynamics and Arts university students were not.

(i.2) Do non-named forces and other kinds of forces act in the direction of forces of resistance?

Figures 7.23 and 7.24 shows, respectively, the frequencies of non-named and other kinds of forces students chose acting in the direction of the force of resistance due to solid friction.

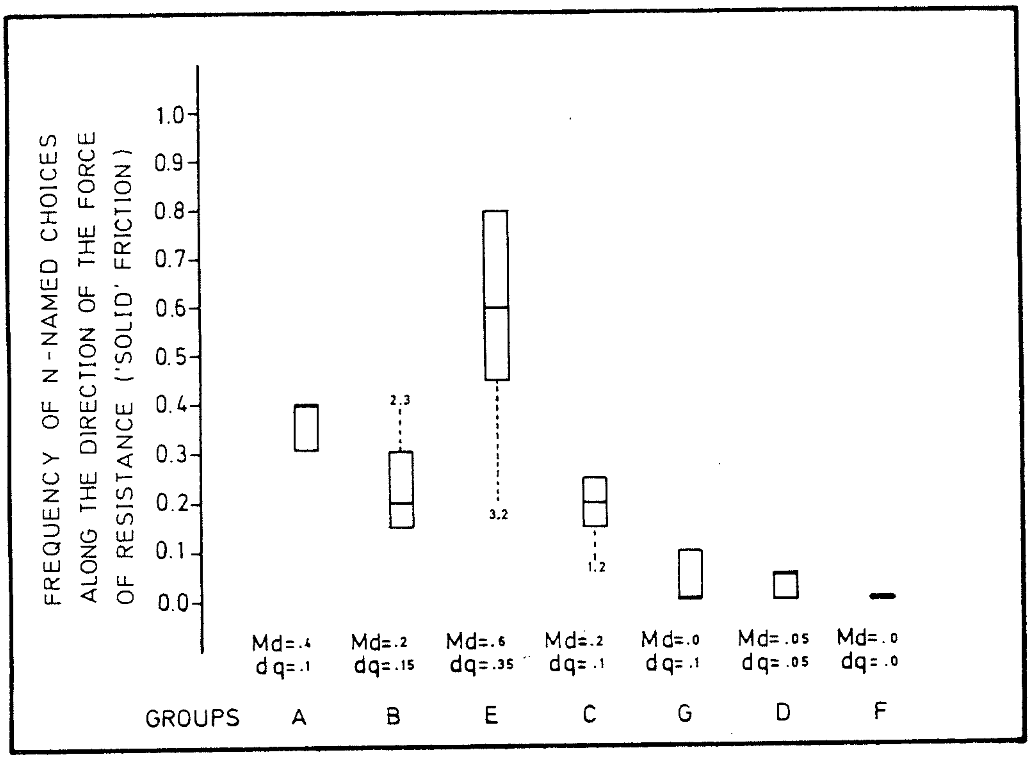


Fig. 7.23 - Schematic plots of frequencies of non-named forces in the direction opposite to motion, for each group, in all situations where objects are moving on solid surfaces

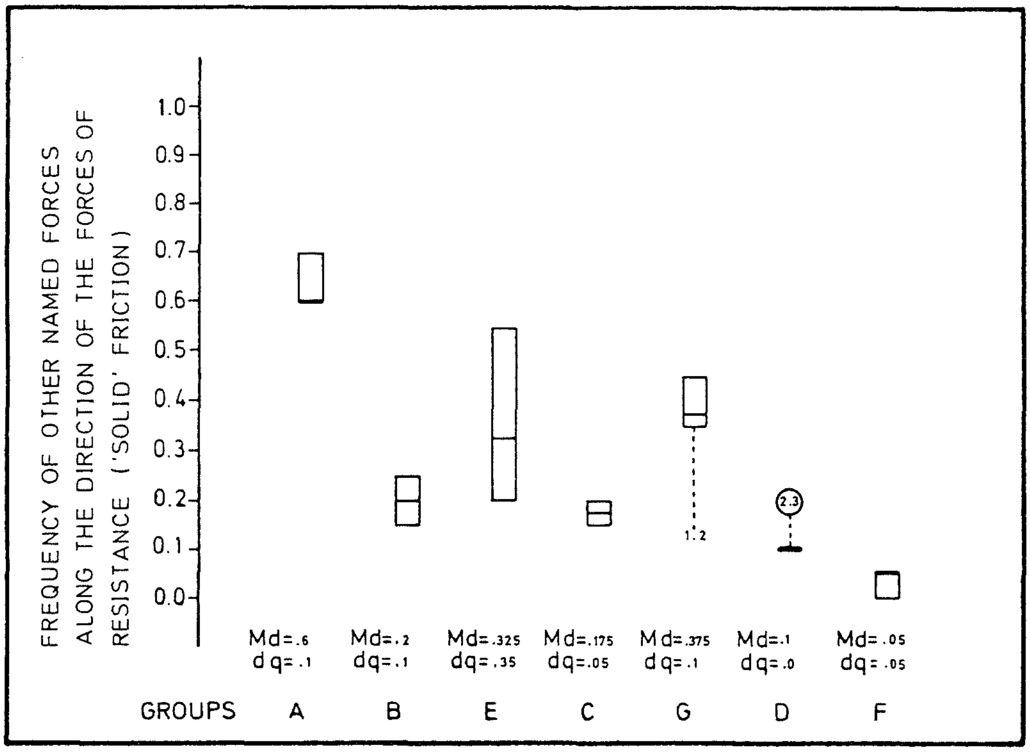


Fig. 7.24 - Schematic plots of frequencies of other named forces acting in the direction opposite to motion, for each group, in all situations where objects are moving on solid surfaces

As expected, students with present formal physics teaching (i.e. groups B, C, D and F), who chose a force along the direction of the force of resistance, rarely non-named it or considered a force of different nature (see in the figures that, for these groups, Md $\leqslant$ 0.2 for both kinds of answers) and did so with small variations across situations (dq < 0.2).

Pupils with no formal teaching in dynamics (i.e. group A) made a majority of choices named differently than expected (see in figure 7.24 that Md = 0.6), again without much variation across situations (dq = 0.1). The names which were mainly given (for example, 'force given by the man' in sit. 1-2, 'impulse' in sit. 3-1) were classified, according to the network presented in sub-section 7.2.3, in the category 'Internal to Object' force/cause. This suggests that these students were not thinking of a force of resistance but about the 'force along the motion', although they had changed the sense of its direction, probably because they associated its direction with the position of the 'source of the action'. A smaller percentage of pupils also named 'air resistance' forces.

Arts university students of group E who chose a force opposite to motion (about 30% as seen in Chapter 6, sub-section 6.2.1.4), mainly did not name their choices (see in Fig. 7.23 that Md = 0.6) but did it with considerable variations across situations (see in Fig. 7.23 that dq = 0.35). However, as seen in sub-section 7.3.2, students of this group did not frequently name their choices of forces at all (only about 35% of the total choices). As with group A, the names given often suggests that these students too were thinking of the 'force along the motion'.

Fig. 7.24 also indicates that a considerable number of choices given by Biologist trainee teachers (i.e. group G) were named differently from expected (about 0.4, in almost all situations). Here the names given suggest that they thought of the force which has only a minor effect in the situations considered, i.e. friction due to the air.

(ii) Do named 'forces of resistance' exist in other directions than the one expected?

Figure 7.25 shows the frequencies of forces named 'friction' which students chose acting in other directions rather than in the direction opposite to motion.

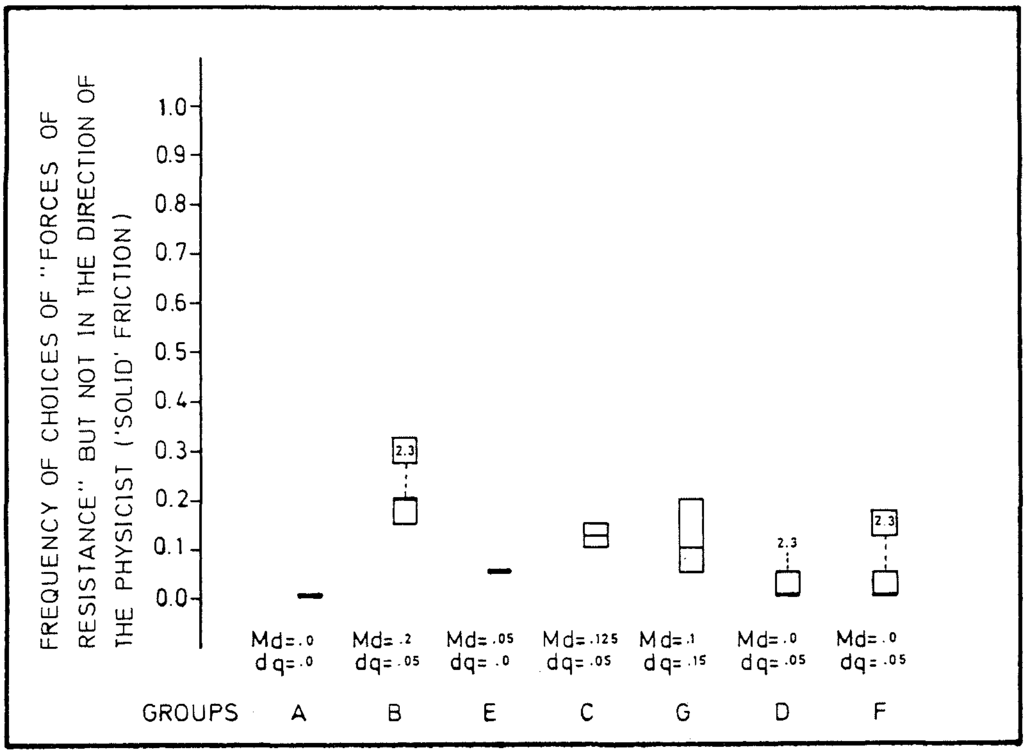


Fig. 7.25 - Schematic plots of frequencies of named 'forces of resistance' acting in other directions that the one expected, for each group, in all situations where objects are moving on solid surfaces

The frequencies of such answers are very small for all groups. It seems that frictional forces are not usually thought of in senses opposed to that of the physicist, except for some students who have just begun their studies about the matter (group B).

(iii) Students' conceptions about forces of resistance due to solid friction

Analysis of individual answers suggested the following categories of replies about forces of resistance due to solid friction:

(iii.1) No Need for Forces of Resistance due to solid friction. This category includes students who never considered such a force. Figure 7.26 shows, for each group, the percentage of students who never considered or named 'resistance forces'/'friction'.

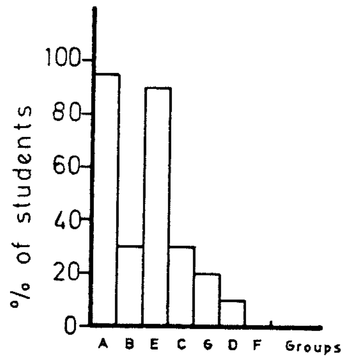


Fig. 7.26 - Percentage of students, of each group, included in the **'No Need for Forces of Resistance due to solid friction'** category

The figure shows that the majority of pupils with no formal teaching in dynamics, and Arts university students, answered without considering forces of resistance/frictional forces at all. In groups with any teaching of dynamics, only a minority failed to consider them, this percentage decreasing with further teaching. It appears that friction is primarily absent from the basic natural scheme of ideas of motion and its causes, being only substantially acquired by teaching, whatever meaning students attribute to such forces. As in other cases, the effect of that teaching seems to fade with time.

(iii.2) **Other Uses of 'Frictional Forces' in situations where objects are moving on solid surfaces.** This category includes students who either chose forces named 'friction' but acting in other directions than expected, or who chose a force opposite to the motion but named it 'air resistance'. Despite the differences between these two kinds of answers, they both suggest that students were thinking of 'resistance forces' other than solid friction.

Fig. 7.27 shows, for each group, the percentage of this category of answers.

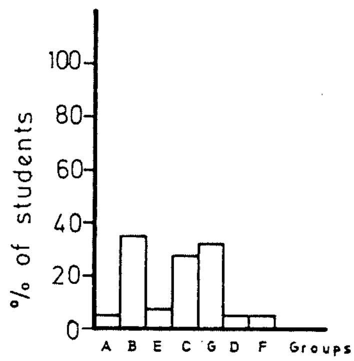


Fig. 7.27 - Percentage of students, of each group, included in the **'Other Uses of 'Frictional Forces' [...]'** category

The percentage of such answers is not high, and is only non-negligible for groups with little or some experience in dynamics (i.e. groups B, C and G). For example, among the 70% of students of group B who considered 'forces of resistance' (see Figure 7.26), 35% did so otherwise than expected. The percentage of such answers decreases substantially, to as little as 5%, for groups with most experience in physics (i.e. groups D and F). For pupils of group A and E, the percentage can be also regarded as relatively high, since it corresponds to all or almost all of the small fraction of these students who chose 'forces of resistance' (see Figure 7.26). These and the earlier results suggest that although a small amount of teaching in dynamics has made students consider 'friction', an appreciable number of them seem not to have fully understood the concept.

One case included in Figure 7.27 is that of 'air resistance'. Figure 7.28 shows the percentages of students naming friction on solid surfaces in this way, compared with the total percentage of answers included in the category under study.

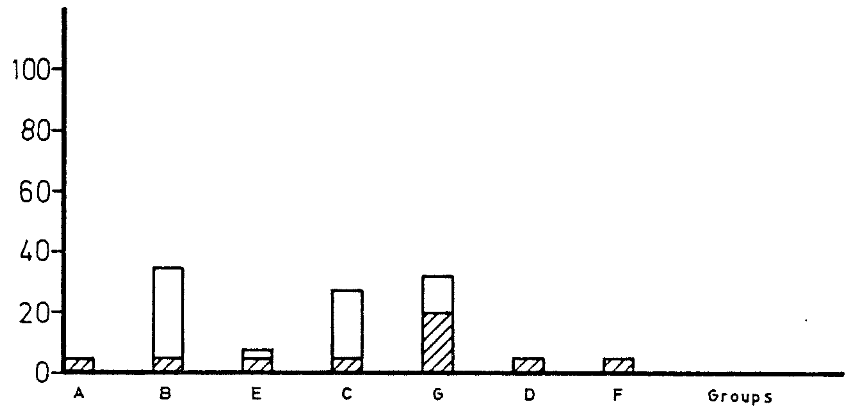


Fig. 7.28 - Percentage of students, of each group, choosing air resistance forces [▨] in situations where objects are moving on solid surfaces, comparatively with the total percentage of cases [□] included in the 'Other Uses of 'Frictional Forces'' category

It can be seen that, except for groups B and C, all or almost all of the students giving other uses of 'frictional forces' did so because they thought of air resistance. This suggests that when teaching in dynamics has not taken place (group A) and/or when it has ceased for some years, resistance to motion, when considered at all, is often attributed to the effect of the air.

A second case of other uses of 'friction', included in Figure 7.27 is that of 'friction' acting in other directions, mainly vertically downwards. In groups B and C these amount to about 30% or more of the total. Perhaps these students see 'friction' as a 'pressing downwards' force which obstructs the motion of an object. This interpretation, however, conflicts for group B (not group C) somewhat with the fact that students of group B also chose 'friction' acting vertically downwards when objects were moving in the air or even when at rest.

Small numbers gave still other responses: 'friction' acting vertically and upwards, and 'friction' acting along the motion.

The main conclusion to be drawn seems to be that the concept of friction seems to be rather often misunderstood by students, at the beginning of their studies in dynamics. One possible reason for this difficulty (which agrees with my own experience with secondary school pupils) is that students find it hard to consider a force **opposite** to the direction of the motion; because they strongly associate forces **with** the motion.

The next two categories occur infrequently, and will be discussed only briefly. They are, however, relevant to the later discussion (7.3.1.3.2) of air resistance.

(iii.3) **Forces of Resistance due to solid friction are Contextualized.** This category includes students who named frictional forces opposite to motion, but who did it only in a few of the relevant situations. Figure 7.29 shows the percentage of such students. It thus seems that solid friction, when considered, is rather uncontextualized.

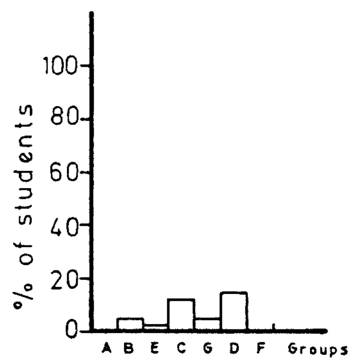


Fig. 7.29 - Percentage of students, of each group, included in the **'Forces of Resistance due to solid friction are Contextualized'** category

(iii.4) **Forces of Resistance due to solid friction are Rarely Contextualized but act, for some situations, in a different direction than the one chosen by the physicist.** This category includes students who chose a force of resistance, in almost all situations, acting in the correct direction, but with exceptions in sits. 2-1 and 2-3 where it was shown acting horizontally to the left. This direction is close to that which a physicist would choose, and coincides with the correct direction in all of the other situations, in which objects are moving horizontally. It may be that these students simply misinterpreted which was the direction opposite to the motion, and that they were therefore answering 'correctly'. However, it could also be that these students always think of friction as acting horizontally; that is, did not fully understood the concept taught. Figure 7.30 shows that such answers, whatever the interpretation, were infrequent.

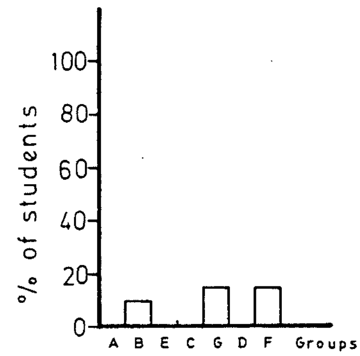


Fig. 7.30 - Percentage of students, of each group, included in the '**Forces of Resistance due to solid friction are Rarely Contextualized [...]**' category

(iii.5) **Forces of Resistance due to solid friction in Agreement with (or close to) the Scientific View.** This category includes students who named frictional forces, opposite to the direction of the motion, in all situations where objects are moving on solid surfaces (it also includes a few students who omitted frictional forces in one or two situations, or considered it acting additionally in other nearly directions). Figure 7.31 shows the percentage of students giving answers in this category.

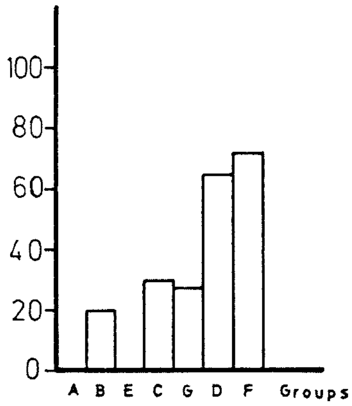


Fig. 7.31 - Percentage of students, of each group, included in the **'Forces of Resistance due to solid friction in Agreement with (or close to) the Scientific View'** category

Pupils who have not had formal teaching in dynamics (group A) and Arts university students (group E), did not choose frictional forces in agreement with (or close to) the scientific view. As soon as teaching in dynamics takes place a minority of students appear to start to give such answers, which only appear substantially for groups with most experience in physics (groups D and F).

Again it appears that the notion of solid friction is a concept essentially acquired by formal teaching and that this concept is only acquired by the majority of students after a considerable amount of teaching in physics, i.e. at the university physics level. Despite the fact that this concept is taught at the secondary school, only a minority of the students at this level seem to think of friction in complete agreement with what they have been taught.

7.3.1.3.2 Forces of Resistance due to air friction

(i.1) Are forces acting in the direction of forces of air resistance usually named as expected?

For the direction opposite to the motion, in situations where objects are moving in the air and not on solid surfaces, one would expect students to choose a force of resistance, giving it a name such as air resistance/air friction or even only friction. Figure 7.32 indicates the frequency of choices named in this way, relative to the total number of choices of a force in that direction.

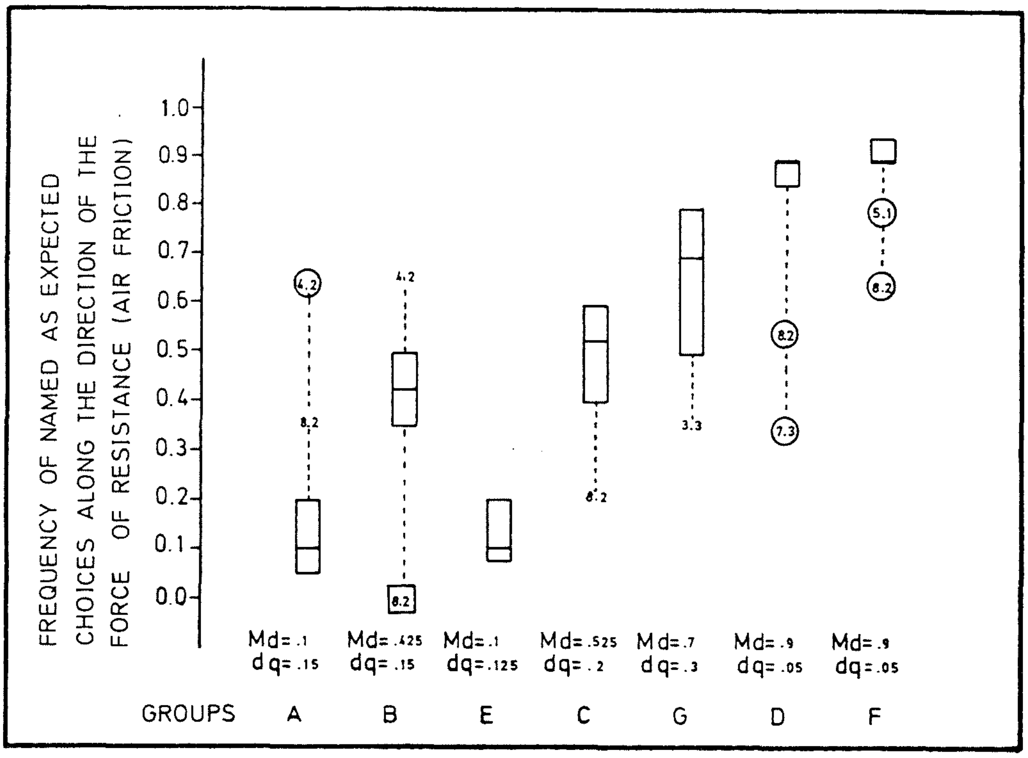


Fig. 7.32 - Schematic plots of frequencies of named-as-expected forces in the direction opposite to the motion, for each group, in all situations where objects are moving in the air

Generally, the results indicate a substantial increase in students naming their choices as expected, with teaching in dynamics. Thus, while very few pupils without any teaching gave answers as expected (Md = 0.1), the number of such answers increases for groups with some teaching (Md = 0.425 for group B and Md = 0.525 for group C), continuing to increase for groups with most experience in physics, where the majority of students' answers were as expected (Md = 0.9). The majority of Biologist trainee teachers of group G also named their choices as expected. As in many other cases the results for Arts university students are similar to those of group A.

The results also indicate that variations with situations are, generally, rather low (dq ⩽ 0.3, with an exception for group G) but that there are some extreme cases.

These data are consistent with the discussion in Chapter 6, sub-section 6.2.1.4 and 6.2.2, where it was suggested that, only at the university physics level, do the majority of the students think of air resistance forces.

(i.2) Do non-named forces and other kinds of forces act in the direction of forces of air resistance?

Figures 7.33 and 7.34 show, respectively, the frequencies of non-named and other kinds of forces that students chose acting in the direction of the force of air resistance.

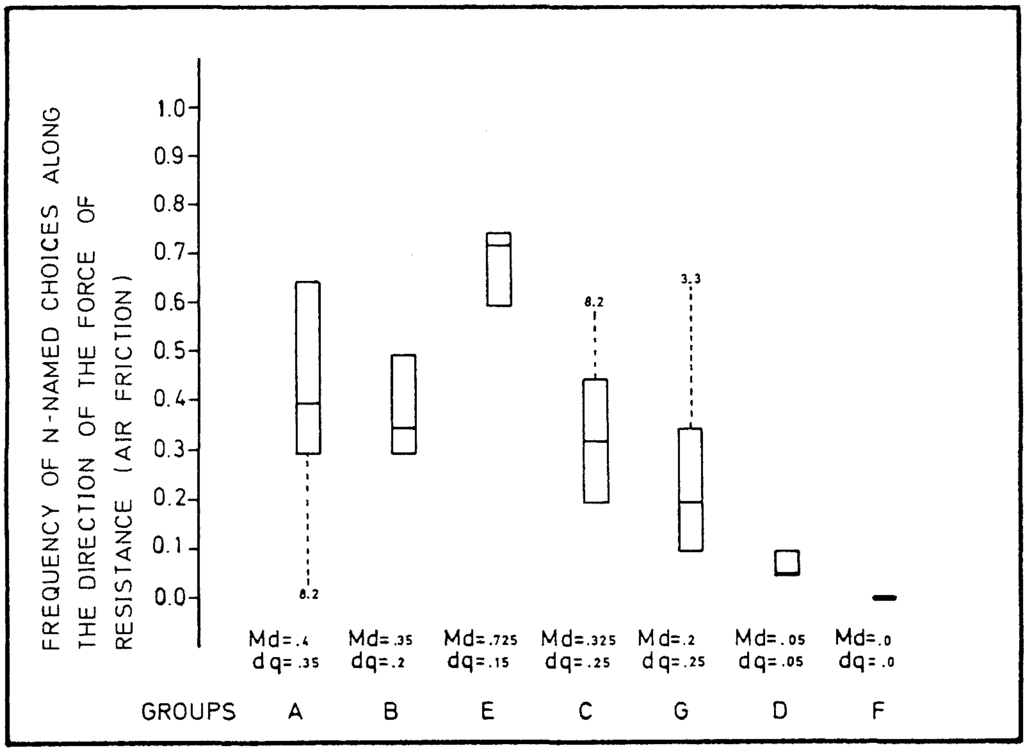


Fig. 7.33 - Schematic plots of frequencies of non-named forces in the direction opposite to the motion, for each group, in all situations where objects are moving in the air

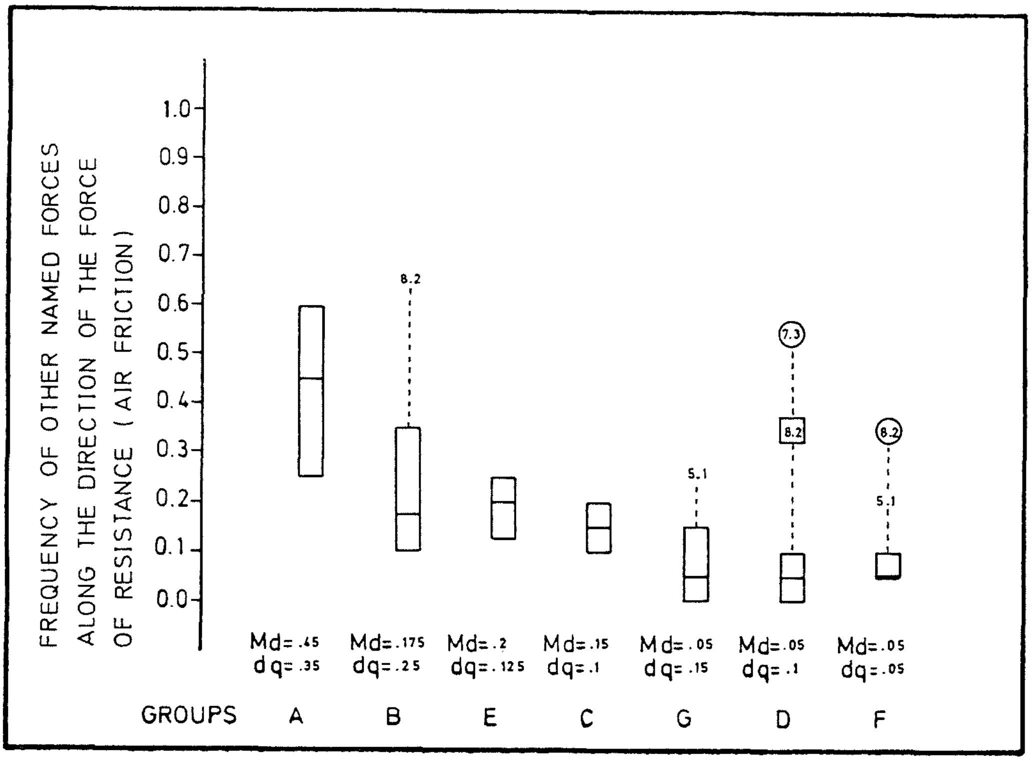


Fig. 7.34 - Schematic plots of frequencies of other named forces acting in the direction opposite to the motion, for each group, in all situations where objects are moving in the air

Comparing the two Figures it can be seen that students who did not name the force 'air resistance' most often did not name the force at all, and less often gave names of other kinds. This suggests some tendency to be surer that a force of this kind exists, than of what to call it, but the inferences one can make here can hardly go further than that. Not giving a name (Figure 7.33) also shows appreciable variations with situations (dq $\geqslant$ 0.2 for groups A, B and C), suggesting that students' uncertainty about a name is dependent on the situation presented. Indeed the discussion in Chapter 6, sub-section 6.2.2, has already pointed out a dependence of students' ideas about forces opposite to the motion with the context of the situation.

Giving a name other than air resistance, though generally less frequent (see Figure 7.34) is however done in an appreciable number of answers by pupils of groups A (Md = 0.45). These names mainly refer to forces associated with the motion and, most probably, just represent a force 'along the motion'. Notice that a similar phenomenon was seen for this group, in the discussion of solid friction. Sit. 8-2, a man diving into a swimming pool, presents special problems, attracting more than usual numbers of other named responses.

(ii) Do named 'forces of air resistance' act in other directions than the one expected?

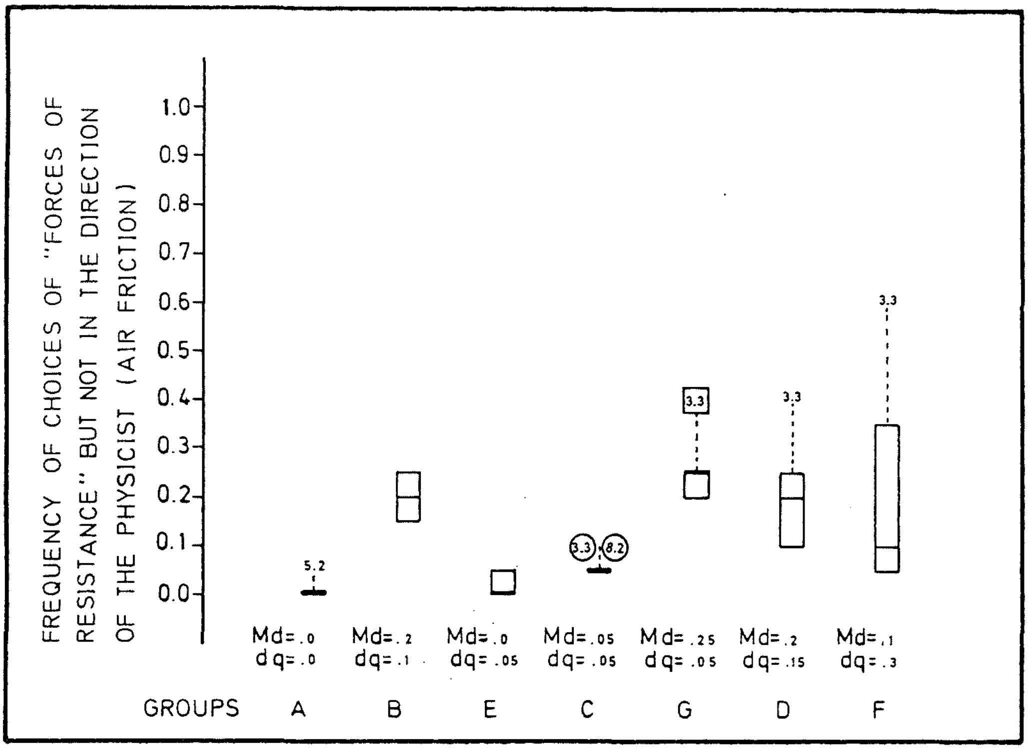


Figure 7.35 – Schematic plots of frequencies of named 'forces of air resistance' acting in other directions than the one expected, for each group

Figure 7.35 showing the frequencies of students' choices of forces named air resistance/resistance force/friction, in other directions than opposite to the motion indicates that:

(a) generally, for all groups, the frequency of such answers is not high (Md $\leqslant$ 0.25, zero for groups A and E) but that it increases with teaching. This seems to agree with earlier suggestions that the concept of resistance is often not fully understood;

(b) for groups with some and most experience in physics, variations with situations are relatively large, suggesting that students' choices of air resistance in other directions are contextualized.
As suggested in Chapter 6, sub-section 6.2.1.4, it seems that air resistance forces, when chosen, are considered in directions other than merely opposite to the motion.

(iii) Students' conceptions about forces of resistance due to air friction

Analysis of individual answers, in all situations where objects were not moving on solid surfaces, suggested the following categories of replies about forces of air resistance:

(iii.1) **No Need for Forces of Air Resistance.** This category includes students who never gave the name 'air resistance' to forces acting in the direction opposite to the motion and/or in any other direction. Figure 7.36 shows, for each group, the percentage of this category of answers.

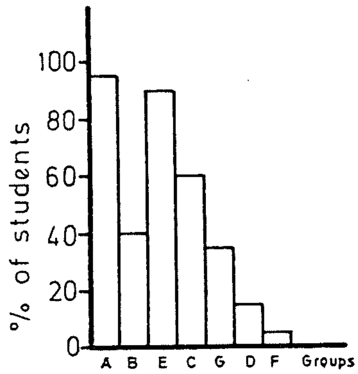


Fig. 7.36 – Percentage of students, of each group, included in the **'No Need for Forces of Air Resistance'** category

Generally, this data shows that the need to consider forces of air resistance only occurs, for the majority of students with teaching in dynamics. However, it seems that this effect of teaching is not real, at least for the first few years, because **(a)** it seems to fade with time (Arts university students gave similar answers to those of the pupils of group A), **(b)** by the end of secondary school, students (of group C) chose forces of air resistance less often than students who had just begun their studies in dynamics (group B). This last result is particularly interesting. One possible reason for this outcome may be that school like situations are usually treated in ideal conditions, i.e. by neglecting friction, particularly air friction, so that more teaching causes air resistance to be ignored.

It appears then that forces of air resistance are primarily absent from pupils' minds, not being effectively incorporated, at least until the end of secondary school. Notice that this seems to confirm what was pointed out in Chapter 6, sub-section 6.2.2.

(iii.2) **Other Uses of 'Air Resistance' Forces.** This category includes students who named an 'air resistance' force, in all or almost all situations considered, but who did it in such a way which suggest that they hold a different view of that force. The number of these cases is very small, being zero for almost all groups, occurring only (never more than 10%) for groups with a little teaching in dynamics. Figure 7.37 showing the percentages of such answers illustrates this fact.

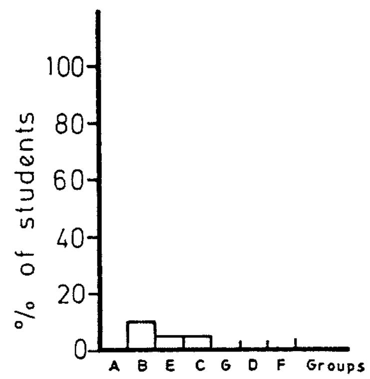


Fig. 7.37 - Percentage of students, of each group, included in the **'Other Uses of 'Air Resistance' Forces'** category

(iii.3) **Forces of Air Resistance are Contextualized.** This category includes students who chose air resistance forces only in some of the situations presented (see Figure 7.38).

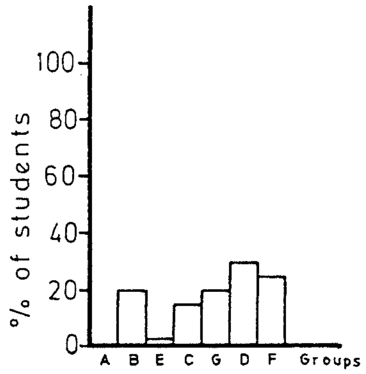


Fig. 7.38 - Percentage of students, of each group, included in the **'Forces of Air Resistance are Contextualized'** category

The results indicate that the percentages of these answers are not high for any group. By comparing, for each group, the number of these answers with the total number of replies of the choices of air resistance forces, one notices a tendency for students with less experience in physics to consider more often air resistance only in some situations than students with more experience. No clear pattern about the situations where air resistance was more often chosen did, however, emerge from the inspection of students' responses. In conclusion, one can not make any clear statement about the contextualized nature of air resistance choices. Moreover, the results above do not also show any strong dependence of students' choices of air resistance with the context (this being not in agreement with what was expected from the discussion given in Chapter 6, sub-section 6.2.2).

(iii.4) **Forces of Air Resistance are Rarely Contextualized but act, for some situations, in a different direction than the one chosen by the physicist.** This category includes students who chose forces of 'air resistance' in all or almost all of the situations considered but acting, for some situations, in another direction than the one chosen by the physicist. The alternative directions were, mainly, vertically and upwards and/or nearby directions opposite to the motion. Figure 7.39 shows, for each group, the percentage of students who gave these answers.

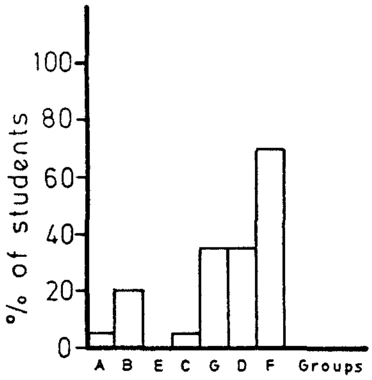


Fig. 7.39 - Percentage of students, of each group, included in the **'Forces of 'Air Resistance' are Rarely Contextualized [...]'** category

The results indicate that, apart from group E, who, in general, did not choose air resistance forces, students of all the other groups gave these answers, substantially. The percentage is notably high for Physics trainee teachers of group F, where the majority of the students gave these answers. Notice, also, that although only 5% of pupils of group A gave such answers, this percentage corresponds to the total number of pupils who chose air resistance forces. As was argued previously with respect to solid friction, two interpretations can be given to this outcome. The first is that these students simply misinterpreted which was the direction opposite to the motion and, therefore, appeared to answer differently to the physicist. However, it can also be that these students did not fully understood the concept. The evidence given in this study is not, however, sufficient to make any decision on this matter. Interviews with students to find out their explanations for these kind of replies, would be needed.

Figure 7.40, showing the frequencies of answers with forces in unexpected directions, relative to the total number of students considering air resistance forces helps to show which were the more problematic situations. As pointed out previously (see, Chapter 6, sub-section 6.2.1.4), this Figure confirms that sit. 3-3 (a ball falling down from a table) attracted substantially more of such answers (here, with forces directed vertically upwards). The results also show the presence of other cases, notably sit. 8-2 (a man diving into a swimming pool): in this case students opted for a nearby direction.

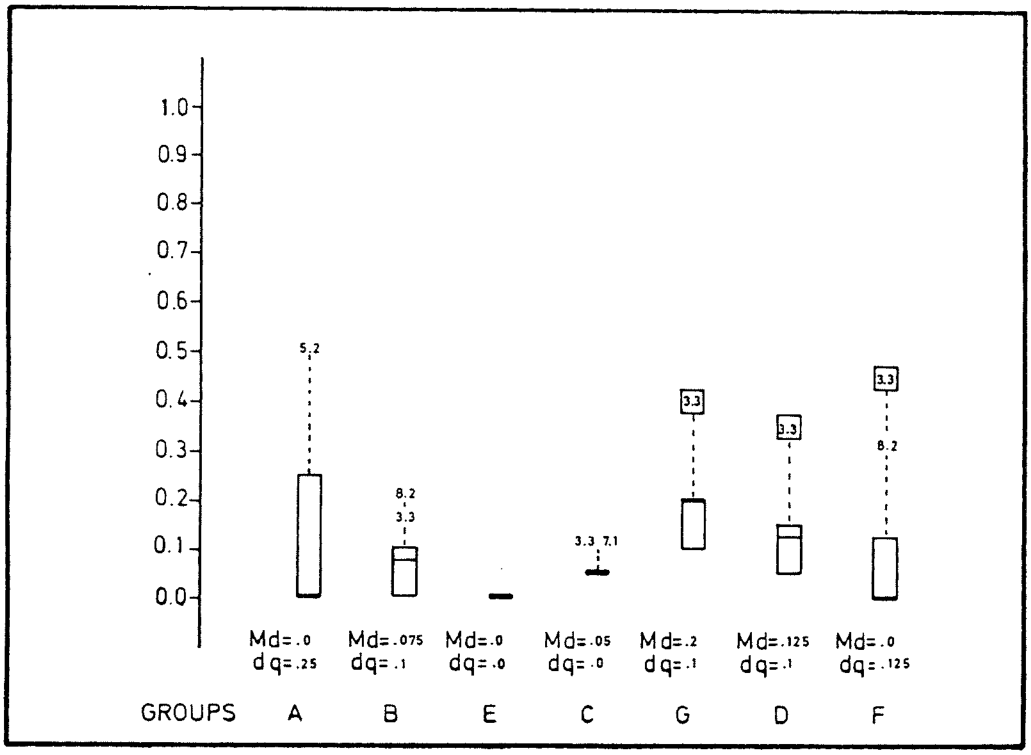


Fig. 7.40 - Schematic plots of frequencies of students choosing air resistance in other directions than expected, for each group, in all situations

(iii.5) Forces of Air Resistance in Agreement with (or close to) the Scientific View. This category includes students who chose and named an air resistance force in all situations considered, acting always in the expected direction. It also includes some students who occasionally omitted to put such a force (see Figure 7.41).

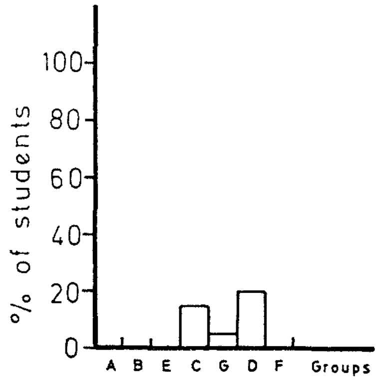


Fig. 7.41 - Percentage of students, of each group, included in the **'Forces of Air Resistance in Agreement with (or close to) the Scientific View'** category

The percentage of students giving answers in complete agreement with the physicist's point of view is rather low (never higher than 20%). This is, particularly, striking for groups at the university physics level. However, as mentioned before, the perecentage of students at this level, considering forces of air resistance on a rather uncontextualized basis is substantially higher, mainly for Physics trainee teachers, although this may not mean that students fully grasp the concept.

These results seem to confirm that the notion of air resistance is a concept essentially acquired by formal teaching and, probably, not by the majority of students, even after a considerable number of years of formal teaching.

7.3.1.3.3 Comparative analysis of students' answers of forces of resistance due to solid and air friction

In order to compare the most striking features of students' answers with respect to forces of resistance, due to solid and air friction, I have decided to combine, for each case, all students who considered such forces, except the cases included in the 'Other Uses of 'Frictional' Forces' categories. Figure 7.42 shows, in comparison, the frequencies of students of each group who gave such answers, in all situations. The dotted boxes correspond to solid friction and the plain one to air resistance.

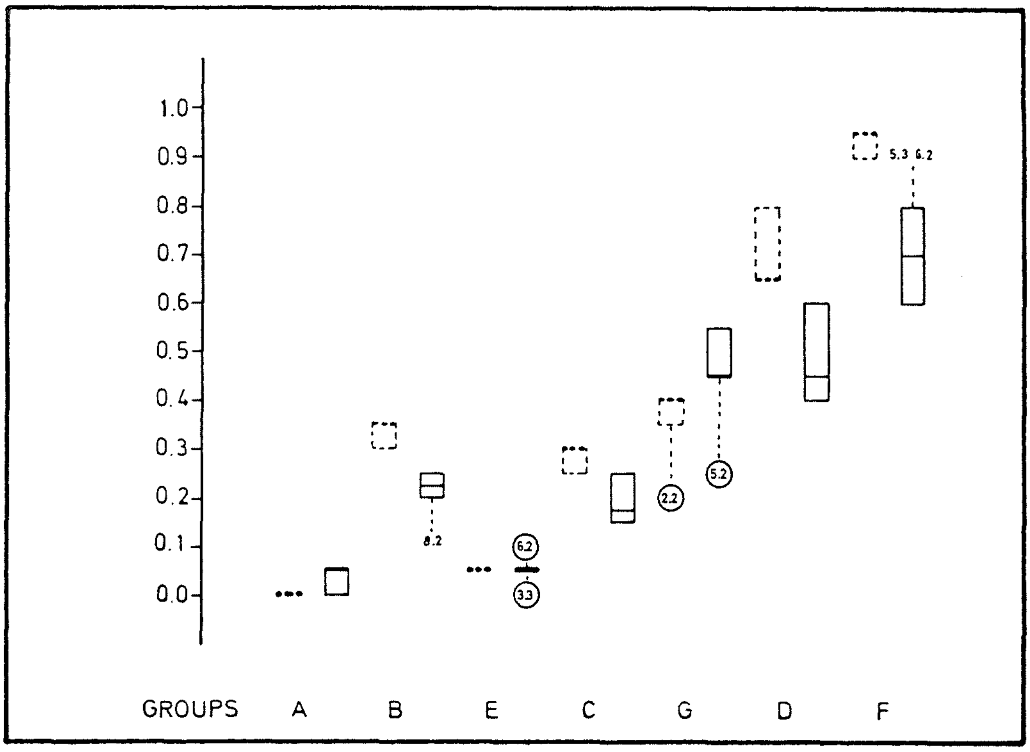


Fig. 7.42 - Comparison of the schematic plots of frequencies of students considering forces of resistance due to solid (dotted boxes) and air friction (plain boxes), for each group, in all situations

Generally, the results indicate:

(a) for all groups with experience in physics, except group G, students more often chose solid frictional forces than air resistance, this being more noticeable for groups with most experience in physics. Thus, for example, while the majority of students of group D chose, in almost all situations, solid friction (Md = 0.65), only about 45% of them chose air resistance forces.

Remembering the discussion given in the two previous sections, one can also say that solid friction was more uniformly chosen among situations and, mainly, directions, than was air resistance;

(b) although variations with situations are generally low (dq $\leqslant$ .2), for both kinds of answers, they slightly increase for choices of air resistance.

Notice also that the presence of extreme cases is more noticeable for air resistance forces.

It appears that students more often consider forces of resistance when objects are moving on solid surfaces than in the air. It also appears that friction, when considered, is better grasped when it concerns solid friction than when it is air resistance.

Despite these differences, the results have the same trend for both kinds of replies, with a gradual increase of students considering forces of resistance with teaching.

7.3.1.3.4 Forces of resistance due to water

Since only one situation (sit. 8-3), concerned forces of resistance due to water, the discussion here is very brief. The information obtainable is further limited by the fact that the direction of the water resistance is essentially the same as that of gravity, in the case presented.

Apart from group F, in no case did the fraction of students in a group mentioning resistance due to water, in any direction, exceed 25%, or the fraction giving such a force in the expected direction exceed 5%. For group F, 25% gave the force as expected, with a further 10% mentioning it but not in the expected direction.

7.3.2 'Intuitive' forces

7.3.2.1 Impulsive forces

As discussed in Chapter 6, sub-section 6.2.1.5, the results for situations where the physicist would choose an impulsive force were not all clearcut, and it was suggested that an analysis of names could help to understand some of these results. For this reason, the discussion here treats separately the results of the less problematic situations (sit. 1-1, kicking a ball, and 6-2, throwing a ball) and then the results of those which were more problematic (sit. 6-3, catching a ball, and 8-1, jumping from the springboard).

7.3.2.1.1 Impulsive forces caused by a man kicking and throwing a ball

(i.1) Are forces acting in the direction of the impulsive force usually named as 'expected'?

For the forces acting in the direction of the impulsive force, one would expect students to give them names such as 'force exerted by the man on the ball' or just 'impulsive force'. Some other names were also given by students to this force which, although differing from the expected designations, were also counted here. These names refer to words usually attributed, by the scientist, to other physical quantities as, for example 'energy (given by the man to the ball)'. The reason for including these names here was, mainly, because they also suggest that students were thinking of the action of the man.

Figure 7.43 shows, for each group, the percentage of both kinds of answers in each of the situations considered. For any group, the first column corresponds to the results found in sit. 1-1 and the second to those of sit. 6-1.

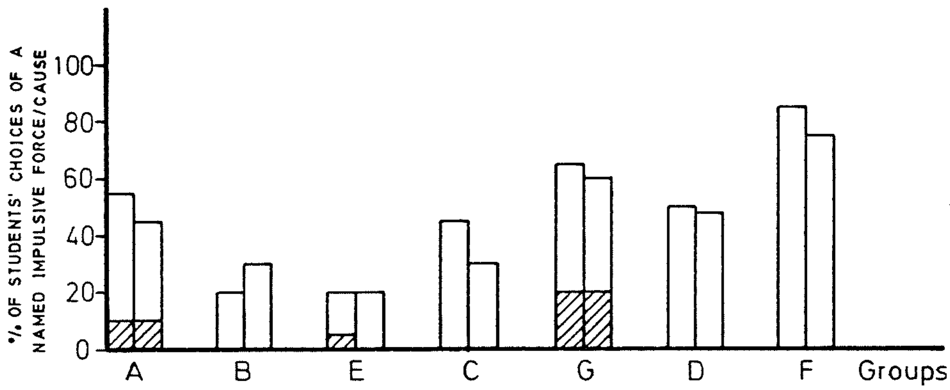


Fig. 7.43 - Percentage of students' choices, for each group, of named answers as expected (□), and other names (▨), in sit. 1-1 (first column of any group) and in sit. 6-1 (second column)

Despite what was referred to in Chapter 6, sub-sections 6.2.1.5 and 6.2.2 - V, particularly in what concerns the similarities, between groups and situations, in students' choices of a force along the direction of the impulsive force, the results here indicate the presence of striking differences in students naming their choices as 'expected', mainly between groups. Thus, for example, while about 50% of the choices given by pupils of group A were named as expected, this percentage decreases with the first year of teaching (group B), increasing again, a little for group C and up to 50% for first year university physics students of group D. Only for trainee teachers, were the majority of the replies named as 'expected'.

The variations between the two situations considered are rather small, although there was for most groups, a slight decrease of forces named for sit. 6-1.

The occurrence of other named causes is also not very frequent, and it is interesting to notice that they only occurred for groups with no present or no previous formal teaching in dynamics (i.e. groups A, E and G). This suggests that teaching has inhibited responses with 'unscientific' names.

(i.2) Do non-named forces and other kinds of forces act in the direction of the impulsive force?

Figures 7.44 and 7.45 show, respectively, the percentages of non-named and other kinds of forces that students chose acting in the direction of the impulsive force.

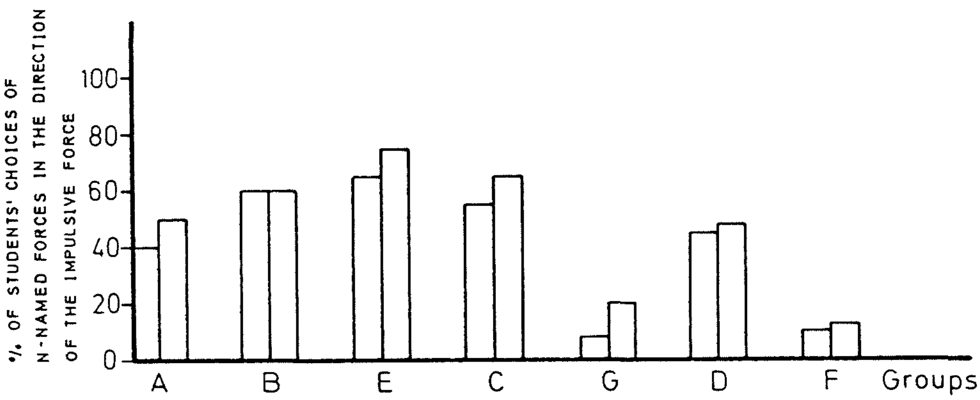


Fig. 7.44 - Percentage of students' choices, for each group, of non-named answers in the direction of the impulsive force, in sit. 1-1 (first column of any group) and in sit. 6-1 (second column)

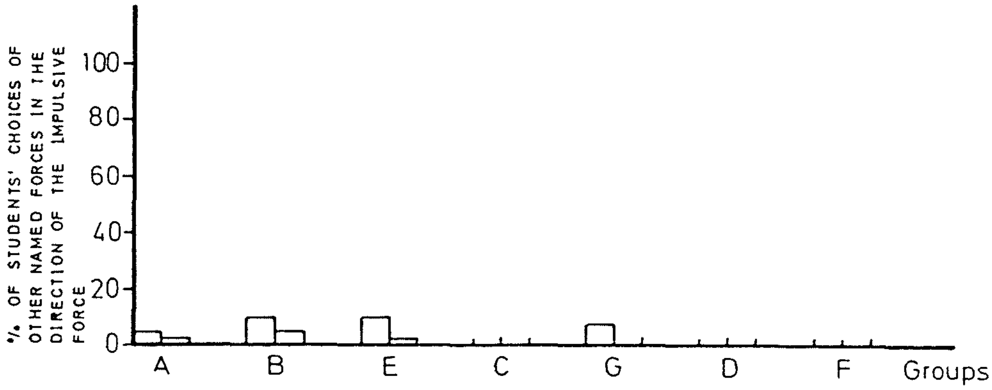


Fig. 7.45 - Percentage of students' choices, for each group, of other named forces in the direction of the impulsive force, in sit. 1-1 (first column, of any group) an in sit. 6-1 (second column)

As expected from the foregoing, the percentage of these answers is, generally, fairly high, but only for non-named forces. The percentage of other named forces (see Fig. 7.45), for all groups and in both situations, is either zero or very small (never higher than 10%), indicating that students very rarely considered other forces acting in the direction of the impulsive force. Thus, it appears that a considerable number of students of all groups, except groups G and F, were sure of the existence of an impulsive force, but less sure about the name to give to it.

Going back to the results shown in Figure 7.43, one may now attempt to explain the striking differences between groups. The main feature is that the groups with current experience of learning physics name impulsive forces less frequently than those with no such experience, or those training to teach physics. Current teaching may somehow inhibit their naming of such force. This is in contrast to the results in sub-section 7.2.3, where it was noted that the tendency with these groups is for the majority of replies to be named. Notice also that the previous analysis of 'acquired' forces also generally indicated for these groups a higher percentage of forces named as expected.

(ii) Do impulsive forces exist in other directions than the one expected?

In the situations where an impulsive force is involved, given that for some groups impulsive forces are often not named, forces in directions other than the expected one were looked for, whether named as such or not (provided that there was not another clear interpretation, e.g. reaction forces). Indeed, the data showed that both kinds of answers were given, for almost of the cases, in the same alternative directions.

Figure 7.46 shows, for each group, the percentage of these answers, in the sit. 1-1 and 6-1.

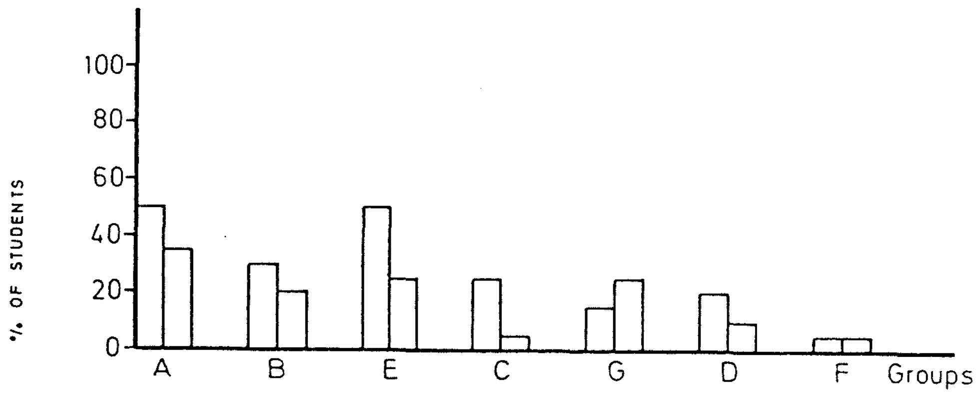


Fig. 7.46 - Percentage of replies, for each group, of choices of an impulsive force in other directions than the one expected, in sit. 1-1 (first column, of any group) and in sit. 6-1 (second column)

Generally, the results show that such answers were rather often given by pupils without any formal teaching in dynamics and Arts university students (about one half of the answers, for sit. 1-1). This percentage decreases, considerably, with teaching. Notice that, generally, more of these answers were given for sit. 1-1, than 6-1. The most frequently chosen alternative directions were, towards the agent, i.e. opposite to the actual direction of the impulsive force, and 'undirected' directions, i.e. along the correct direction but also opposite to it.

Given (1) that the kinds of alternative directions mostly chosen seemed also to be related with the man's action, and (2) that they were mainly chosen by groups with no or no recent teaching about forces and (3) that the percentage of such answers is substantially reduced with teaching, it appears that these answers also indicate that students were thinking of an impulsive 'force', although they did not yet associate the force with the correct and/or a unique direction.

(iii) Students' conceptions about impulsive forces

Answers about impulsive forces can be described by just one category because, (1) few situations are involved, (2) non-named replies need to be included (see above), and (3) nearly all answers shared one main feature.

Analysis suggested the following category of replies about impulsive forces:

(iii.1) Need for an Impulsive Force/Cause when there is an external action on an object. This category only excludes students who either did not choose any force or chose only other forces, such as gravity, Reaction. It also excludes other rare cases in which the answers were not interpretable.

Figure 7.47 shows, for each group, the percentage of students who were included in this category, in sit. 1-1 and 6-1.

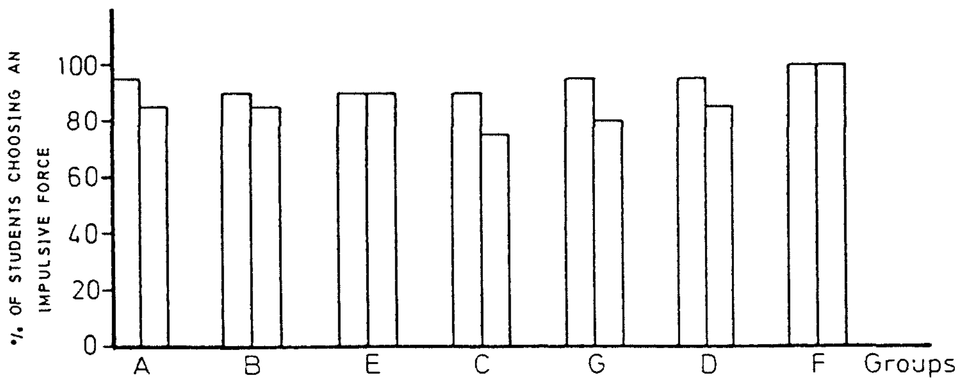


Fig. 7.47 - Percentage of students, of each group, included in the **'Need for an Impulsive Force/Cause (...)'** category for sit. 1-1 (first column, of any group) and sit. 6-1 (second column)

The results confirm what was mentioned in Chapter 6, sub-sections 6.2.1.5 and 6.2.2 - V, that the majority of students of all groups needed a force/cause for the instantaneous action of the man on the ball. This suggests that, at least kicks and throws are treated, even before any formal teaching in dynamics, as a case where a 'force' is present. Obviously, this should not be understood as being the same as saying that students of all groups share the same concept about impulsive forces, and not at all about what a force is. Actually, the results discussed before already showed differences among groups, namely, in naming this force and in giving it a direction. Nevertheless, it may be no less important to identify what students think (believe) about motions and their causes, despite the differences which may arise from students' verbalizations of what a force is.

7.3.2.1.2 Results found in sit. 6-3 and 8-1

As mentioned before, the results for choices of an impulsive force in sit. 6-3 (catching a ball) and in sit. 8-1 (jumping from a springboard) were rather different from those of sit. 1-1 and 6-1, presenting, in addition, some difficulties of interpretation. An analysis of names given to forces in the two problematic situations was done, but turns out to be rather inconclusive. For this reason it will no be presented here but in Appendix IV.

7.3.2.2 Force Along the Motion

Given the kind of the force to be studied here, which does not generally exist from the physicist's point of view, the way of looking at the data ought to be different from that used before with respect to the other kinds of forces, particularly in what concerns names given to these forces. Thus, and despite that the general questions addressed here are the same as before, namely about naming versus non-naming forces and about the directions in which these forces acted, greater attention will be given here to the names used by students. Special attention will also be given to the possible differences which may have existed with respect to the nature of the forces chosen and the situations.

(i) Are choices of a force 'along' the motion named?

A remark should be made firstly about the meaning attributed here to the designation force 'along' the motion in that it does not only include choices of a force acting in the direction of the motion but all the choices of a force suggesting that students were thinking of a force associated with the motion. Thus, for example, the answers often given, by some groups, in sit. 3-2 and 5-2 of a force along the future motion [see the discussion in Chapter 6, sub-section 6.2.1.1 or 6.2.2 - (i)] are also studied here. This decision was taken on the grounds that the important aspect to explore here is the naming versus non-naming of forces associated with the motion.

Figure 7.48 shows, for each group, the frequency of named choices of a force 'along' the motion, in all of the situations where objects are moving.

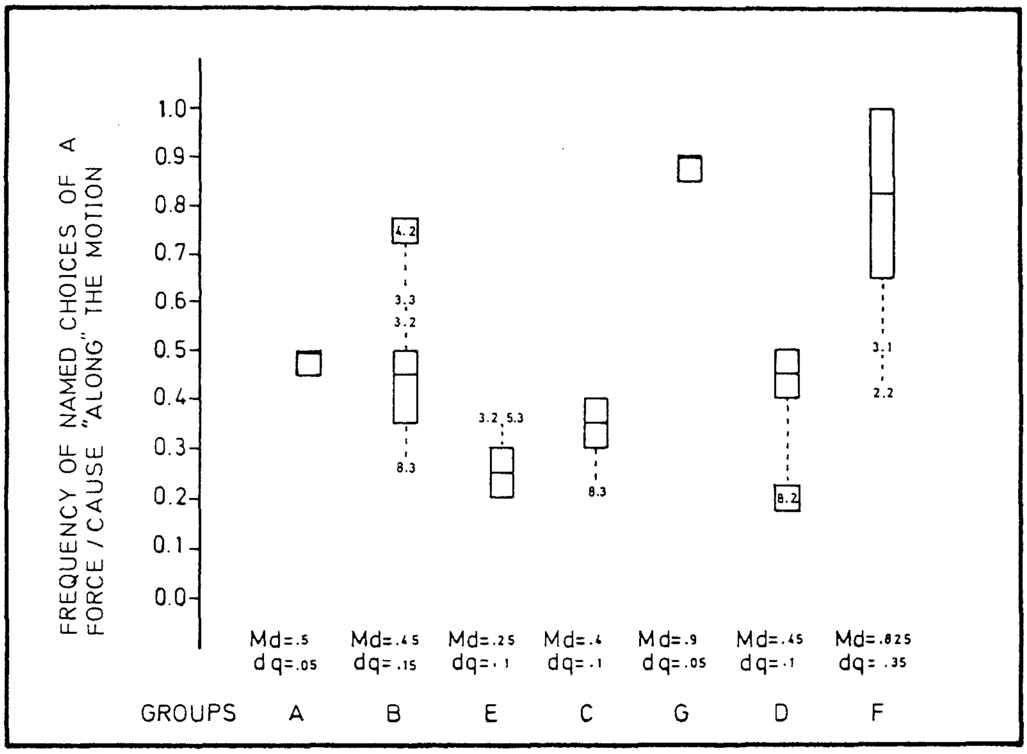


Fig. 7.48 - Schematic plots of frequencies of named choices of a force 'along' the motion, for each group, in all situations considered

For all groups, except G and F, only about one half, or less, of the choices of such a force were named, suggesting that students were more sure about the existence of a force 'along' the motion than about the name to be given to it. Notice that these results are particularly representative since they are taken from a large number of students' choices [see Chapter 6, sub-section 6.2.1.1/6.2.2 - (i)]. Notice also that, as with the results found for the impulsive force, groups with experience in physics generally named such a force less often than usually. For example, while about 90% of the choices given by physics university students of group D were named (see sub-section 7.2.3), this occurs here only with about 45% of the choices. This suggests that more intuitive forces are less often named than are forces acquired by teaching. This is not unexpected because teaching, in principle, does not reinforce the notion of a force associated with the motion.

The high frequency of named forces found for groups G and F should not be taken too seriously since they correspond to a small number of students, mainly for group F who, remembering the discussion given in Chapter 6, sub-section 6.2.1.1, did not usually consider such a force.

The results also indicate that variations with situations are generally low ($dq \leqslant 0.15$), although there are some extreme cases, for some groups, where the frequencies are higher/lower. It is interesting to notice that the cases where these frequencies are higher, always correspond to situations where objects are falling freely (e.g. sit. 4-2, a tree falling down, sit. 3-3, a ball falling from a table).

Not much information about names given to the force 'along' the motion was obtained in this study, since generally only one half or less of the students' choices were named. The names mostly given by students to this force will now be discussed, looking in particular at differences between groups and situations.

(i.1) Forces 'along' the motion: nature of the forces and differences between groups and situations

The analysis of the names given to the force 'along' the motion was guided by the network discussed in sub-section 7.2.3. Remembering the categories defined there, and given the kind of the force under study here, one might expect that a considerable proportion of replies would have been included in the **Internal to Object** category. Figure 7.49 shows, for each group, the frequency of internal named choices, relative to the total number of named answers, in all of the situations considered.

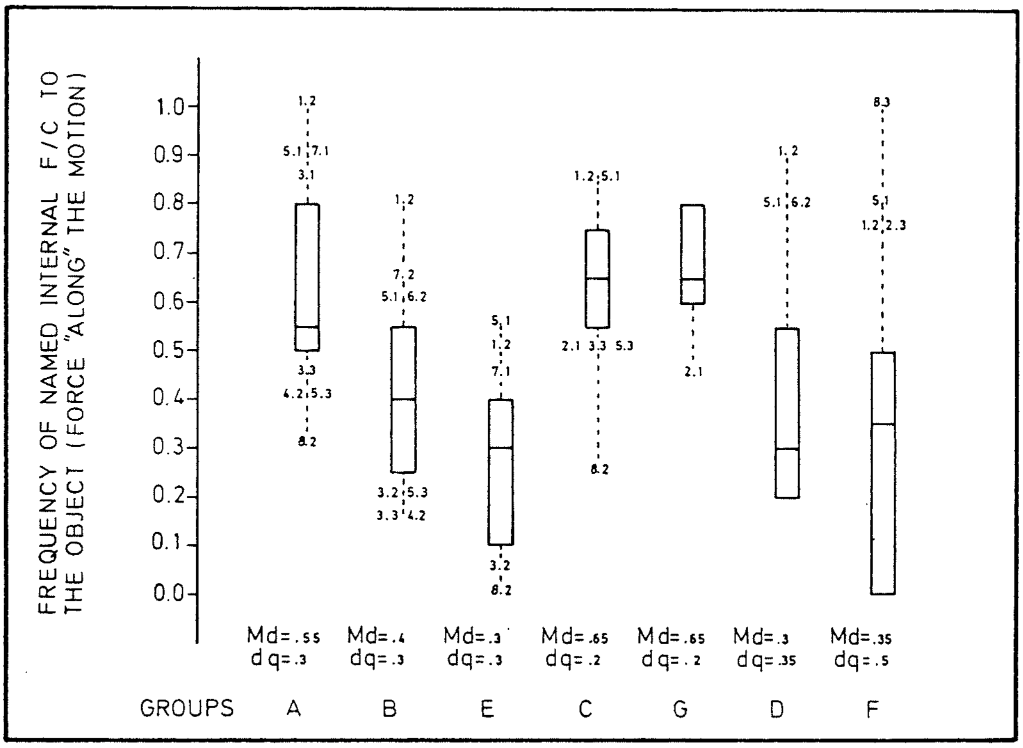


Fig. 7.49 – Schematic plots of frequencies of named choices of force 'along' the motion included in the **Internal to Object** category, in all situations considered

The most striking feature of these results is the large variation with situations, dq is quite large (dq $\geqslant 0.2$) and there are many extreme cases. The extreme cases generally correspond to two sets of situations: **(a)** where internal named choices are more frequent than usual (e.g. sit. 1-2 and 5-1) and **(b)** where such choices are less frequent, these being mainly situations where objects are falling freely, or are about to fall, (e.g. sit. 3-3 and 4-2).

The results described above suggest that the notion of a force 'along' the motion varies markedly with the kind of situation presented; that some internal cause may be responsible for some kinds of motions but not for others.

With respect to differences between groups (though not so noticeable as those between situations) there is a tendency for a reduction of internal named choices, for those groups with most experience in physics. As will be seen next, this reduction is mainly due to the fact that a considerable number of these students named their choices component/net forces. Arts university students, generally, did not also seem to give so often internal named choices, but here because their answers were unclassified.

In order to explore further the nature of the forces associated with the motion, a more detailed discussion follows, concerning the names attributed to such a force in the different situations.

Table 7.IV illustrates, in greater detail, the most common replies which were given by any group (usually more than 50% of the total named answers), according to the categories defined in the network used (see sub-section 7.2.3), in some of the situations. An additional specification of the most common cases included in the **External to Object** and **Unclassified** categories was also done. The letters, in any cell of the Table, correspond to the notation always used before to designate the different groups.

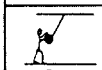
	INTERNAL TO OBJ.			EXT. TO OBJ.		UNCLASSIFIED	
	F/C PAST COND.	FUNCT. STATE	PROP. OF OBJ.	GRAV./ WEIGHT	OTHERS	?	CT / NET FORCE
 1.2	A B E C D	G F				E	
 5.1	A B E C G D F	B G					
 7.1	A B E C					E	D F
 8.3			A B E C D F			E D	
 3.3	C	G		A B E C			D F
 5.3	C	G		A B E C			D F
 8.2				A B E C			D

TABLE 7.IV: Most common categories/sub-categories of named replies given, by each group, to the force 'along' the motion, for some situations

One interesting aspect of the results seems to be that there are notable differences in the names given to the force 'along' the motion in different situations. For example, whilst when a ball is moving on the ground (i.e. sit. 1-2), students seem to think mainly of a 'force' **in** the object, the force seems to be **external** to the object when a ball is falling downwards (e.g. sit. 3-3). Even when a 'force' internal to the object is needed to continue the motion, its origin seems to depend also on the context of the situations. Thus, for example, whilst for a cannon ball to move upwards in the air (sit. 5-1), it has to carry the 'force' given by an external cause (the cannon), when a man is coming up in a swimming pool (sit. 8-3), the 'force' seems now to be generated by the man.

The results shown in Table 7.IV also point to interesting aspects, now relating groups, they are:

(a) students of a given group who named their choices seem to share identical views about the force 'along' the motion, in any situation. Actually, one sees from the Table that, for any situation, each group usually gave only one kind of reply;

(b) students of groups D and F, who considered a force 'along' the motion, showed a curious behaviour. They often named such a force 'component'/'net' forces. Figure 7.50 showing, for these two groups, the frequency of such named choices relative to the total number of named forces 'along' the motion, in all situations considered, illustrates that the tendency was for the majority of university physics students' choices to be named 'components'/'net' forces (Md > 0.5). Given that (1) such names were not usually given, by these groups, with respect to the other kinds of forces studied before, (2) these names were not only given in the directions, and situations, where the physicist could have putted them (e.g. in sit. 2-1) but also in others (e.g. in sit. 6-2), these results suggest that the scientifically trained student labelled her/his intuitive beliefs with scientific terms. A similar suggestion has been already made by other researchers (e.g. Viennot, 1983, Osborne and Freyberg, 1985).

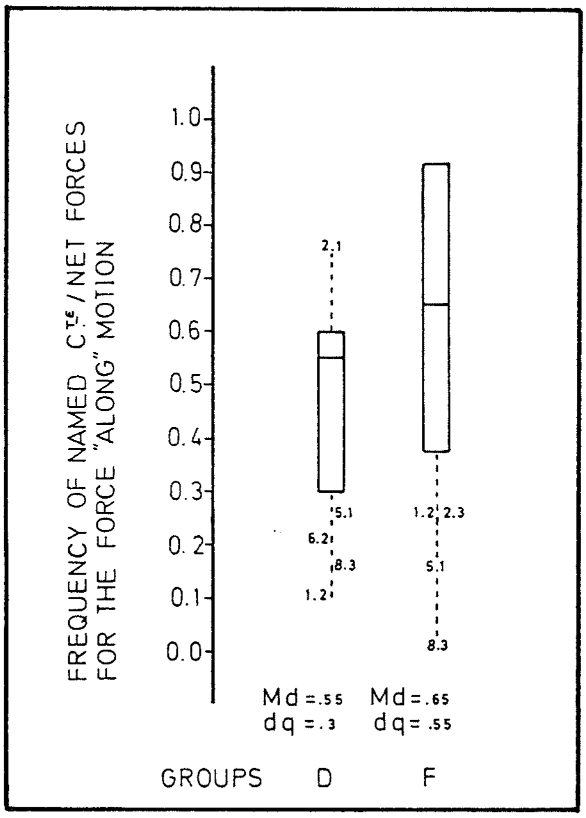


Fig. 7.50 - Schematic plots of frequencies of named **'components'/'net' forces** for the force 'along' the motion, for groups D and F, in all situations

(ii) Do forces associated with the motion act in other directions than along the motion?

Figure 7.51 shows, for each group, the frequency of students' choices suggesting a force associated with the motion, acting in other directions than along the motion, in all situations considered.

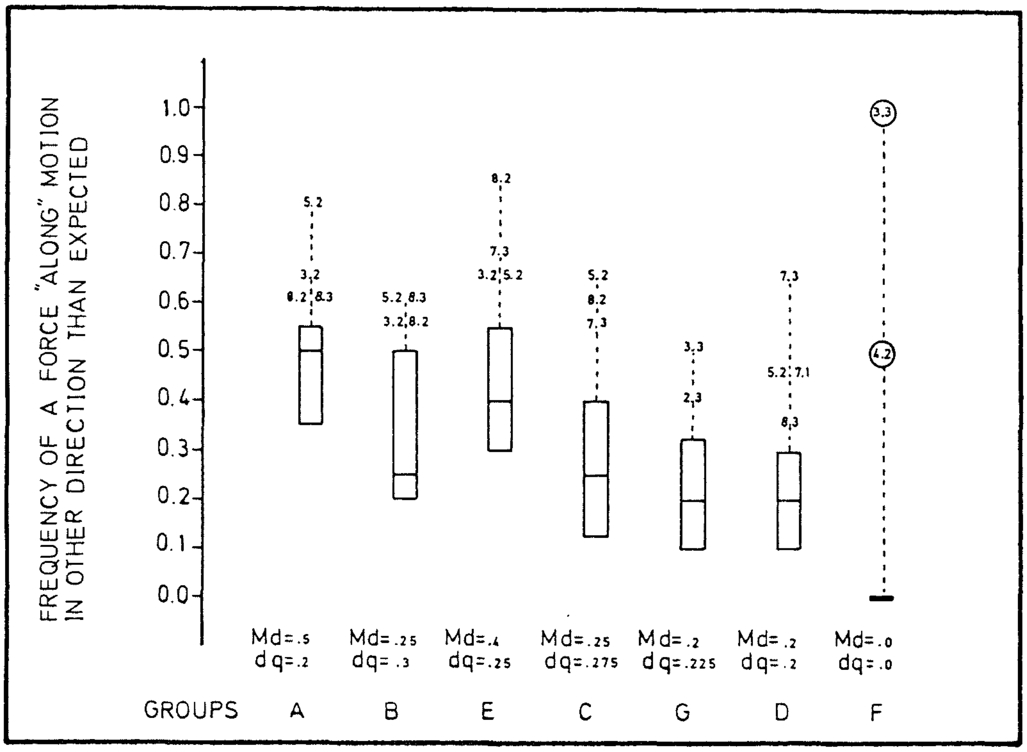


Fig. 7.51 – Schematic plots of frequencies of choices of a force associated with the motion, acting in other directions than along the motion, for each group, in all situations considered

The tendency for students to choose a force associated with the motion in directions other than 'expected' is generally low (Md ⩽ 0.25), and appears to decrease with teaching. There are, however some extreme cases where such answers were generally more frequent. These include the two situations where a change in the direction of the motion is about to occur where students opted for a force in the direction of future motion, a result expected from the discussion of Chapter 6, sub-section 6.2.1.1/6.2.2 – (i). Sit. 8-2 (a man diving into a swimming pool) and 8-3 (a man coming up in a swimming pool) were also extreme, with, respectively, choices in the downward vertical direction and upwards to the right. This could be understood as students having changed the direction of the motion. if so, these cases are not really exceptions.

(iii) Students conceptions about a force 'along' the motion

Given that (1) students' choices of a force 'along' the motion (including, here again, all the forces associated with the motion) were, frequently, non-named and that (2) for some groups and in some situations, it often acted in other directions than the one 'expected', the analysis of individual answers looked here only at the general question of whether or not each student considered such a force in the different situations, the evidence being collected not only from named choices in the 'expected' direction but from all the answers suggesting that students were thinking of a force associated with the motion. This analysis suggested the two following categories of replies.

(iii.1) **A Force 'Along' the Motion Exists and is Rather Uncontextualized.** This category includes students who usually considered a force associated with the motion in all/almost all of the situations presented. Figure 7.52 shows, for each group, the percentage of students who were included in this category.

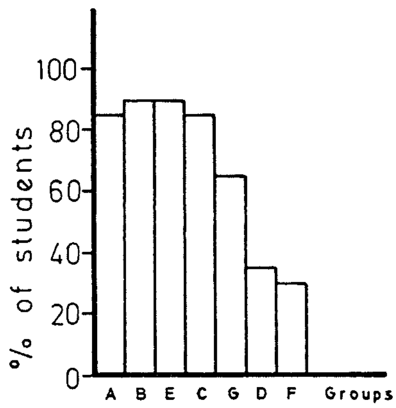


Fig. 7.52 - Percentage of students, of each group, included in the **'A Force 'Along' the Motion Exists and is Rather Uncontextualized'** category

The results agree with the suggestion in Chapter 6, sub-sections 6.2.1.1 and 6.2.2, that the majority of students of almost all groups gave answers suggesting the need of a force associated with the motion in many situations. This percentage is only substantially reduced for physics university students of groups D and mainly F. This seems to confirm that, at least for students with physics experience up to the end of secondary school, the intuitive notion of a force associated with the motion exists and prevails in students' minds and that this notion is rather independent of the context.

(iii.2) A Force 'Along' the Motion Exists but is Contextualized. This category includes students who considered a force 'along' the motion but only in some situations. Students who usually considered that such a force existed except, mainly, in situations where objects are falling freely were included here and special attention is given to them. Figure 7.53 shows, for each group, the percentage of students included in this category. It also shows the percentage of students who generally avoided choosing such a force where objects are falling freely.

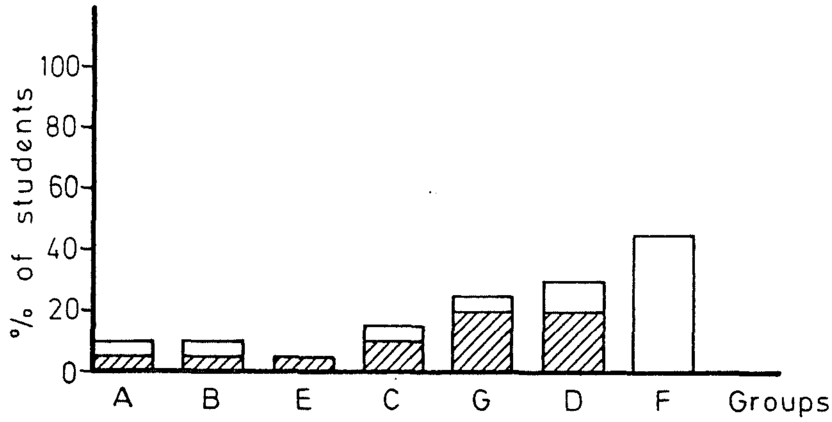


Fig. 7.53 - Percentage of students, of each group, included in the '**A Force 'Along' the Motion Exists but is Contextualized**' category (shaded section, no choices where objects fall)

The results indicate that the percentage of students considering a force associated with the motion in certain contexts increases with teaching, this being most noticeable for university physics students of groups D and F and also for Biologist trainee teachers. Remembering the results discussed earlier, this suggests that even after several years of formal teaching in dynamics, an appreciable number of students continue to consider a force associated with the motion, although not in all situations. The results also indicate that for all groups, except group F, the situations where a force 'along' the motion tends to be absent correspond, mainly, to those involving objects falling freely. As pointed out before, this may be due to the fact that gravity functions there as the cause for the object to keep moving.

CHAPTER 8

INTERPRETATIONS AND CONCLUSIONS

In this final chapter there are three sections. The first, **Summary of the Results**, presents, as a preliminary, a brief synthesis of the main results discussed in Chapters 6 and 7. The patterns of the ideas which students of each group seem to hold about the 'force'/causes needed to explain/describe 'everyday' like situations are, there, brought together. The second section, **Possible Interpretations**, atttempts to give an account of how these results may be understood. The interpretations suggested there are mainly based on ideas from a theory of Commonsense Reasoning about motions proposed by Ogborn (1985) and from some personal views about the nature of children's knowledge about dynamics (those outlined in Chapter 3, sub-section 3.1.3). The last, **Concluding Remarks and Suggestions for Future Research**, presents the main contributions of this research and proposes issues for future investigations.

8.1 – Summary of the Results

The aim of this section is to bring together the patterns of ideas students of each group seem to hold and which were suggested by students' choices of directions of forces (analysed in Chapter 6) and by the additional information obtained from the names given to the forces chosen (analysed in Chapter 7). This seems to be a convenient thing to do in that it will help to promote the discussion of the aspects to be interpreted.

Figure 8.1 gives a picture of the main results found, for each group except G, concerning the five kinds of forces mostly chosen by students. The decision to omit group G from this discussion was mainly because there is no obvious way to compare it with other groups (see discussion in Chapter 7, at the end of sub-section 7.1.2) and also because of the small number of students (N = 16).

The following procedures were used to build the picture shown in Figure 8.1:

(a) to group the results into three main categories

(a1) **Force hardly exists (HF)** - where 70% or more of students' replies (including directions of forces chosen and names given) suggest that a particular kind of force does not exist (shown in the figure, by a blank square, □)

(a2) **Force exists but only for some students (SF)** - where between 50% and 70% of students' replies suggest that a particular kind of force does not exist (shown in the figure, by a shaded square, ▒)

(a3) **Force exists for the majority of students (MF)** - where more than 50% of students' replies suggest that a particular force exist (shown, in the figure by a black square, ■)

(b) to distinguish the cases where the results found, for any of the categories defined above, present other characteristics than those suggested by the name used to designate the force. For example, the case where a majority of students of a group considered 'gravity' but where 50% or less of the replies suggest that students were thinking of gravity differently from the physicist. (These cases are marked, in the figure, by a square with an 'R' inside the representation of the respective result).

(c) the designation given, here, to each kind of force is the same to the one used in the two previous chapters. Force 'along' the motion includes, here, choices of forces associated with the present and future direction of the motion

(d) the results exclude those which were seen in the two previous chapters as being problematic. For example, results about impulsive forces exclude those found in sit. 6-3 (catching a ball) and 8-3 (jumping from a spring-board).

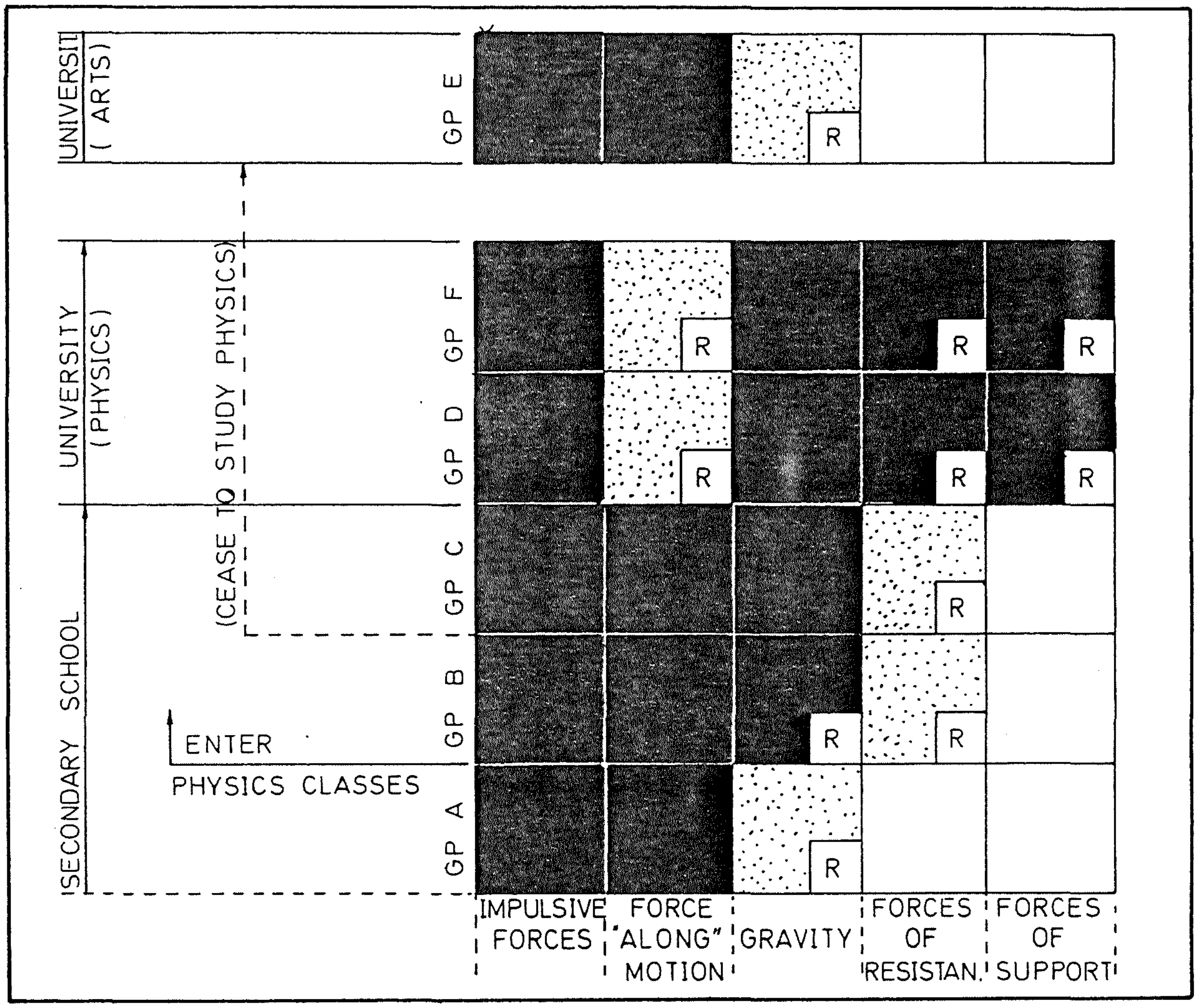


Fig. 8.1 - Summary of the results, of each group except G, concerning the five kinds of forces mostly chosen (☐ - force hardly exists (HF), ▨ - force exists for only some students (SF), ■ - force exists for most students (MF), R - when there is a discrepancy between students' ideas and the 'accepted' meaning of the force considered)

A summary of the main results suggested by the figure above is given next.

(i) Before entering Physics classes (group A), students seem to hold common ideas about which forces/causes are needed (and not needed) to explain/describe everyday dynamical events. Namely, a majority seem to need a force/cause to explain (i1) **why objects start moving** (a majority chose impulsive forces in all situations considered), and (i2) **why objects keep moving in a given direction** as well as **changes in the direction of the present motion** (a majority chose, in all situations, a force 'along' the motion). **Resistance to motion** and **support** do not seem to need a force/cause to be explained (a majority did not choose forces of resistance and forces of support). **'Gravity'** is only considered by some students and, often, only in situations involving objects falling (or about to fall) freely in the air where it 'acts' along the motion (see Chapter 7, sub-section 7.3.1.1). Thus, gravity (as the ever present interaction between the earth and the objects) does not seem to be taken into account by the students.

(ii) When students are taught about the concept of force (group B), a majority of them seem to maintain the need to consider a force/cause to explain/describe (ii1) **why objects start moving** and (ii2) **why objects keep moving in a given direction** as well as **changes in the direction of the present motion**, despite this being not in agreement with the physicist's view. **Support** seems to be kept as something not needing a force/cause to be explained/described. **Resistance to motion** appears to start being taken into account, although by only some students and mainly only in situations where it is due to solid friction (see Chapter 7, sub-section 7.3.1.3). Resistance due to air and water seem to be neglected. **'Gravity'**, however, is now often considered by a majority of students in almost all situations, but less than 50% seem to hold its scientific meaning (see Chapter 7, sub-section 7.3.1.1).

(iii) Students with some teaching in dynamics (namely, about Newton's laws) at the end of their secondary school studies (group C) seem to hold, in general, similar views as those described above for group B, except concerning **gravity**. This force appearing to be now understood in the physicist way, by a majority.

There are, however, some small improvements, but only for a few students, with respect to the orthodox understanding of solid friction and Reaction forces (see the results, of groups B and C, shown in Fig. 7.21 and 7.31, in Chapter 7). Moreover, the results described in Chapter 7 also indicated that students of group C tended to have a better grasp of the concept of force as having a unique direction, than students of group B.

(iv) Generally speaking, the majority of students at their first years of university studies in Physics and Engineering appear to need to consider the four kinds of forces a physicist would choose in the situations presented. However if a majority appears to have the orthodox meaning with respect to the notions of impulsive forces and gravity, the same can not be said for forces of resistance (except if they are due to solid friction) and forces of support. Forces of resistance due to the air and, mainly due to water are not considered except by few students (see Chapter 7, sub-section 7.3.1.3.2 and 7.3.1.3.4). The same occurred for forces of support, in this case because students often chose a 'vertical Reaction' force on sloping surfaces (see Chapter 7, sub-section 7.3.1.2).

Moreover, and despite the disagreement with what students have been taught, a force 'along' the motion (here only along the direction of the present motion) continues to be needed, although by only some students, except in situations where objects are falling (or about to fall) freely in the air (see Chapter 7, sub-section 7.3.2.2).

(v) Generally, Physics trainee teachers (group F) appear to give similar answers to those of group D. However, some changes, although small, occurred towards more 'correct' scientific views. For example, a few more students chose **(a)** forces of support in agreement with the scientific view (see Fig. 7.21, in Chapter 7), **(b)** forces of resistance due to water (see Chapter 7, sub-section 7.3.1.3.4). Also, less students chose a force along the motion in an uncontextualized way (see Fig. 7.51, in Chapter 7, sub-section 7.3.2.2).

Given that a small number of students of this group (N = 18) were involved in this study, for more conclusive results one should look at a bigger sample.

(VI) As has been mentioned several times already, Arts university students (group E) give very similar answers to students of group A, despite having a similar Physics background than students of group B.

In conclusion, one may say that our results suggest that students enter Physics classes with a definite and common set of intuitive ideas about which 'forces' are needed (and not needed) to account for everyday dynamical events. Physics teaching, at least up to the end of secondary school, appears to have 'added' to it other notions. Some (like gravity) appear to be more readily understood by students than others (like forces of resistance, and mainly forces of support). Despite that, and at least if students had little experience with dynamics, these acquired notions seem to fade with time, the primitive ideas winning in the end!

A considerable amount of experience in Physics (university level) seems to have had real effects (see Chapter 6, sub-section 6.2.2), although one can still trace some 'residuals' of students' intuitive ideas. Moreover, it seems that there are difficulties associated with the full grasp of some of the acquired notions (i.e. resistance forces due to air and to water, 'Reaction' forces when objects are on sloping surfaces).

8.2 – Possible Interpretations

This section attempts to give some interpretations for the results summarized in the previous section. The interpretations to be given are mainly based on ideas derived from a theory of Commonsense Reasoning about motion, proposed by Ogborn (1985), and from some personal views on the nature of children's knowledge about dynamics (see Chapter 3, sub-section 3.1.3). The four following views/beliefs will constitute the core of the subsquent discussion:

(i) students' ideas about dynamics come mainly from early **actions** on the world and so, most probably, they have to do with **that** world. It is a world where, for example, persons often have to push/pull objects for them start moving; a world where gravity is ever-present and so generally is friction;

(ii) ordinary persons (and so students in their daily activities) **do not try to explain what is always there** (in the world) or what always happens (as, for example, gravity);

(iii) the **formalization** of students' notions/beliefs about the physical world **is not necessarily made in the same terms as those of the physicist;**

(iv) despite the differences which may exist between scientist's notions and those held by ordinary persons, the last would constitute also a **general and coherent set of ideas.**

A preliminary remark should be made about my claims concerning the interpretations to be given. Obviously I can not say that they are the only possible ones. I will, however, try to show next that they can reasonably explain what is happening.

(a) **Why do students, before entering physics classes, appear to hold the views described in the previous section?** Namely:

(a1) that a force/cause is needed to explain why objects start moving. Or, in other words, why do 'impulsive forces' seem to be so easily and naturally learned?
The interpretation can be traced back from point (i) presented above. Given that persons' activities on the world often involve actions in which persons have to push/pull on objects for them start moving, and also because certain objects, like balls, do not start moving for themselves if they stay on horizontal surfaces, it seems plausible that such actions/events lead to a natural acquisition of such a notion;

(a2) that a force/cause is needed to explain why objects keep moving and changes in the direction of the present motion.
The interpretation of this result, based mainly in points (i) and (iii) above, calls for the need to look again at the kind of ideas students express about the force 'along' the motion (see Chapter 7, sub-section 7.3.2.2, particularly Table 7.IV). Note, however, that the interpretation which follows is necessarily speculative, given that only about 50% and less of the students gave names to this kind of force.
Although one could interpret the results found as suggesting a diversity of students' meanings for force (e.g. Watts, 1983), it seems more reasonable to look at them from a different point of view. This is to suggest that what is in common is the idea that a 'force'/cause is **needed** to keep motion in all/almost all of the situations, for group A but also at least for groups

with no or only some teaching in dynamics (see Chapter 6, section 6.3.1.1), but that its origins differ with the kinds of motions/events involved. That is, **students have generally associated a 'force' with motion, but have differently conceptualized various everyday life motions/events.** Going back to the results shown in Table 7.IV, this could be seen in that:

- to certain objects, like **balls** but probably not persons, a **'force'/cause has to be given** for them to move under certain conditions, e.g. **when moving on the floor or upwards in the air** but not, probably, in order to fall downwards;
- some objects, like **persons**, do not need such a given 'force' to keep moving because they have their **own 'force'** which makes them move, e.g. when a man is coming up in a swimming pool;
- objects, in their **natural motion of free fall**, do not need a given/own 'force' to keep moving but something else, here, **external** to the object.

The interpretation given above, to which Ogborn's Theory of Commonsense Reasoning of Motion (Ogborn, 1985) brought helpful insights, seems to be also more consistent with the hypothesis that the main source of students' intuitions in dynamics is their interactions with the real world through their actions, rather than language.

Moreover, although speculatively, the results of Table 7.IV also seem to be fairly well explained if one accepts point (iv) above. Namely, in that students (of group A but also of the others) who named their choices seem to share identical views about the force 'along' the motion, in any situation. Thus, suggesting that students' views are better seen as generalized ideas rather than individualized. Further, the results seem to fit also in the interpretation that students' intuitions in dynamics do not come, mainly from language sources. Indeed, if one holds, as I do, that one feature of ordinary speech is that of its relative imprecision, one would expect a diversity of names given to this intuitive idea. This does not seem, however, to have occurred, which seems to be consistent with the interpretation that there is a more universal basis for these ideas, a plausible one being persons' actions on the world;

(a3) that a force/cause is not needed to explain/describe gravity, resistance to motion and support. The interpretation thought of here is that such notions do not belong to the primitive natural scheme of students' intuitive ideas about dynamics, because, generally, the ever-present needs no accounting for (see points (i) and (ii) above).

(a3.1) Absence of gravity

Although gravity does not seem to be taken into account by a majority, some did consider it but only in some situations (see discussion given in section 8.1). A possible interpretation for this result, which has been suggested in other studies (e.g. Watts, 1982), is that students constructed an alternative framework of 'gravity' as being a force which only operates when objects start to fall down and continues until they are at rest. However, if this were the case one would expect that, a student holding this framework, would choose 'gravity' consistently in all situations where objects are falling or about to fall, but this did not, in general, occur. Instead, a given student chose it only in some situations.

Another possible interpretation is that gravity is primarily absent from pupils' minds but that they have heard such words in use and give them a meaning consistent with what they already think, i.e. that a force is needed to explain motion. This, perhaps, would not require, so strongly, the 'status' of internal consistency as if it was a construction about 'gravity'.

(a3.2) Absence of friction

As was mentioned, a possible interpretation for the absence of friction is that the ever-present (or the almost ever-present) in the real world needs no accounting for. Alternatively, perhaps, pupils do not feel a need for an external cause to explain why objects slow down and stop. It is perhaps natural that they think that the stored internal cause which objects **'have'** while moving, is used up during motion. This interpretation is in close agreement with what has been suggested by several other researchers (e.g. Watts and Zylbersztajn, 1981, Watts, 1983).

(a3.3) Absence of forces of support

As was mentioned above, it appears that forces of support are primarily absent from pupils' minds. It seems then that pupils do not see any need to use forces to explain why objects stay on the supports where they are, or which hold them up. A possible explanation for this can be derived from the discussion of Commonsense Reasoning in Ogborn (1985):

> '[...] commonsense reasoning does not ocupy its time and energy explaining why the plates |here, any object| stay on the shelf |here, any support| [...] but regards the shelf - if strong - as a permanent support [...]'.

It is argued that this is because

> '[...] Reasoning about support depends on living in a world with much covalently bonded, stiff, strong and nearly incompressible matter around. We do not notice our bodies deforming the floor and generating an upward force to stop us falling through it'.

This last aspect may contribute to the difficulty of students' understanding of the nature of the forces of support, even within physics teaching.

(b) How can one interpret what happens to the primitive scheme of students' intuitions within formal teaching in Physics?

Generally, the results suggested may be seen as if to the primitive scheme were added some notions (some more rapidly than others) while others persisted, at least up to the end of secondary school. That the 'added' notions seem to fade with time, suggests that they are indeed 'added', not fundamental.

Some of the interpretations which will be given, concerning physics teaching, should be regard as speculative and needing further investigations, given that the present study did not look into the kind of physics teaching students had.

(b1) Impulsive forces persist but tend to be less named with teaching

As the results indicated, impulsive forces are considered by the majority of students of all groups, although current teaching seems to inhibit the naming of such forces (see Chapter 7, sub-section 7.3.2.1).

A possible explanation for this reduction may be a result of school experiences dealing more often with rather formal situations, involving mainly 'academic' forces, like gravity/weight, Reaction forces, with also an emphasis on constant forces rather than on impulsive and change of momentum. This may well help students formalization of constant forces but, perhaps, not do much about more 'intuitive' forces, like that treated here. It would perhaps be interesting to explore this aspect further, not merely to attempt to explain the result found here, but also to see to what extent what one does in the physics class is in contradiction with what has been often suggested in recent literature, that is, that one should start from what the learner already knows.

(b2) Forces 'along' the motion persist, at least up to the end of secondary school

The persistence of this notion, despite its being not in agreement with physics, may be better understood if one considers students' intuitive notions as being structured and belonging to some kind of general theory. It seems to me much more difficult to interpret it if one regards intuitions as probably deriving simply from misunderstandings (McClelland, 1985).

Furthermore, if one follows the view expressed in (a2), namely that students' intuitive ideas in dynamics do not fundamentally rest on what they think a force is, but rather on how they conceptualize everyday life motions/events, a plausible explanation of why students' intuitions are so resistant to change through teaching seems to emerge. That is, given that the school curriculum in dynamics conventionally begins with the concept of force, to change students' beliefs about such concept will not necessarily modify students' ideas about how motions occur.

(b3) 'Acquired' notions (i.e. gravity, forces of resistance and forces of support) are differently grasped and fade with time (at least if physics experience is not great)

(b3.1) Gravity is primarily absent, is rapidly understood with teaching, but fades with time

A first remark should be made here about the inferences made, from students' answers, with respect to their concept of gravity and its agreement (or not) with the scientific view (see Chapter 7, sub-section 7.3.1.1). One should not forget that the questionnaire used only presented a restricted number of situations, in particular only events on the Earth. There is thus no evidence about whether (or not) the concept of gravity is extended to space, or exists only on the Earth, an alternative framework suggested by other researchers (e.g. Stead and Osborne, 1979, Watts, 1982). Therefore, a further investigation would be needed to explore more deeply what students of a given group understand by gravity. Despite this, there is some evidence for concluding about the increased number of students considering gravity within teaching and for its more rapid development than that of forces of resistance and forces of support. One possible reason for this aspect may be that 'gravity' seems to have already its roots in students' minds (see discussion of the results of group A in section 8.1) but not the other two kinds of forces. Another reason may be the less visible effect, in the real world of, for example, the interaction between an object being supported and its support and that of gravity. The fading with time of this notion questions, however, the extent to which gravity was really understood and 'accepted' by students. A possible interpretation, although may be too 'dramatic' and speculative, is that conventional teaching does not have any real effect on students' conceptualizations at least if only at the level of compulsory school. Although requiring further investigations, this issue should deserve great attention.

(b3.2) **Forces of resistance are primarily absent, are then acquired slowly up to the end of secondary school, but fade with time.** Forces of resistance due to solid friction are, however, quicker and better grasped than is friction due to the air and, mainly, than is friction due to the water.

A possible interpretation for the better grasp of solid friction is perhaps because its effect is larger, in real world, than is the effect of air resistance.

An interpretation for the small percentage of students considering water resistance (see Chapter 7, sub-section 7.3.1.3.4) must be very speculative. In science teaching in Portugal, the main force associated with objects in water is very probably an upthrust (curriculum lay some stress on Archimedes' principle). This, together with a general neglect of frictional forces, may account for the results.

(b3.3) **Forces of support are primarily absent, are acquired very slowly up to the end of secondary school but fade with time.** Forces of support appear to be considered for counter-balancing gravity, even by some physics trainee teachers.

An explanation for the difficulty of students grasping and fully understanding forces of support may be traced back from (a3.3).

namely because of the often invisible aspects of the interactions between objects and their supports. Moreover, one of the reasons which have been suggested in the literature (e.g. Ogborn, undated) for students difficulties in dynamics is that **dynamics is uncommon sense.** This aspect is illustrated by Ogborn when he writes about Newton's third law:

> 'Children learn to speak of every force having an equal and opposite one, but the idea makes little sense. It is especially senseless in 'explaining' what commonsense calls support, making a book just resting on the table into a big problem, and often leading to teachers themselves telling lies such as that the weight of the book has its reaction in the upward push of the table'
>
> (Ogborn, undated, pp 4)

The quotation above suggests another source for students' difficulties in understanding forces of support which may account for the kind of answers found before (see Chapter 7, sub-section 7.3.1.2, (iii-3)) in which students continue to consider a 'vertical Reaction' force in situations where objects are on sloping surfaces. If the hypothesis that such answers mean a misunderstanding of the concept of forces of support is correct, special attention should be given to this matter, even when dealing with physics trainee teachers.

In summary, one may points out a possible reason why students' intuitions 'win' with time (at least if physics teaching was not much). That is, generally, because students hold a rather well structured primitive scheme about motions which differs from what they are taught. And because what one conventionally teaches in physics classes, particularly in what concerns Newtonian dynamics, is uncommon sense.

8.3 – Concluding Remarks and Suggestions for Future Research

Although this research does not solve fundamental questions concerning, in particular, the nature and content of students' conceptions about dynamics and their role within school instruction, it seems reasonable to claim that it has added further evidence to the existing picture. A brief synthesis of the main contributions of this study is given next:

(i) it confirms previous findings particularly in what concerns the persistence of students' intuitive ideas despite formal teaching in physics.
The persistence of students' intuitive ideas, despite formal teaching in physics, has been suggested in the literature (e.g. by Clement, 1982, by Viennot, 1979a). However, this suggestion has been made, in most cases on the basis of interpreting results obtained from studies involving different populations and methodologies. In the present study, this suggestion is based on results which emerge from the use of the same methodology with a wide range of students' physics background, making the result more secure;

(ii) it brings up interesting results about the co-existence of intuitive and 'acquired' views.
Notice that this aspect has not been much referred to in most recent studies in the area as, usually, the focus of these investigations is students' intuitive ideas only;

(iii) the results found in this study (namely those referred to, in general terms, in (i) and (ii)) add further evidence to support the kind of recommendations, which have emerged from existing studies in the area, that students' intuitive ideas should be taken seriously in the school context. Furthermore, the results found for groups D and F (respectively, university Physics and Engineering students, and Physics trainee teachers) suggest that these recommendations should not be only given in what concerns secondary school teaching but also at the university level, even when it involves Physics trainee teachers.
This point turns out to be particularly interesting, given that most of the field-work was done in Portugal, a country where the 'history' of this kind of research is relatively 'young';

(iv) the similarities between our results (which come mainly from Portuguese students) with others involving students from other countries, bring further evidence to support the claim that culture and language differences do not seem to have a big effect on the content of students' intuitive ideas in dynamics;

(v) it brings some evidence to support the claim that students' intuitive ideas should be regarded as belonging to a more general and coherent common sense world view which, although requiring further study, may lead to a better understanding of the diverse results which have been identified. Furthermore, the kind of methodology used and the interpretations proposed suggest that one may also reduce diversity in the outcomes of this kind of research if one avoids the formalization of students' ideas in terms of the scientific world view.

The last contribution of this research, to be referred to here, concerns the instrument developed (i.e. the questionnaire). It seems to me that one may claim that it is a reasonable and efficient instrument which may be used within the teaching process (at the secondary school level and at the university level, including in courses for Physics trainee teachers). Its efficiency can be argued for on the basis of its simplicity and the lack of time needed either for its administration or for its analysis. The results found using it suggest ways to make it even simpler, especially, the small number of F answers given (see Chapter 6, sub-section 6.1.2) and the close agreement between choices of force directions and names given (see Chapter 7), for most cases, suggest that its future use may include only choices of force directions. The future use of the questionnaire should, however, be preceded by small improvements, particularly the non-inclusion or the clarification of the two situations which the results found were too difficult to interpret (i.e. sit. 6-3 and 8-1, see Appendix IV), and to mention more clearly, in the questionnaire, the object on which the forces are supposed to act (see discussion given in Appendix III).

Suggestions for Future Research

From this study, some research topics were identified. They will be presented, next, as suggestions for further research.

(i) Further research is called for on the clarification of the nature and content of students' intuitive ideas about dynamics. Namely:

(i1) in what concerns the formalization and testing of a more general model for Commonsense Reasoning about dynamics. Particularly by investigating further the hypothesis, suggested by Ogborn (1985) and also from the interpretation given in section 8.2 (b2), that students have differently conceptualized various everyday life motions/events;

(i2) in what concerns the understanding of how ordinary persons' experiences on the world lead naturally to their developing of a common sense theory like, in particular, the one proposed by Ogborn.

(ii) The evidence suggested by this research that a deeper understanding and a reduction of the outcomes found for students' ideas in dynamics, may be achieved if one avoids to formalize them in terms of the scientific world view, raises the question if this may also occur in other topics (e.g. energy, electricity, etc.). Thus, suggesting that parallels to this study could be made in other topics.

(iii) A problem brought to light with this study was the co-existence of intuitive and 'acquired' (and 'accepted') notions within school instruction. An understanding of this issue seems, in the light of the findings of this study, to deserve further investigation.

(iv) The hypothesis put forward in this study that students' construction of everyday knowledge about dynamics owes a lot to their actions on the world and the 'limitations' of the characteristics of this world (for example by the ever-present nature of gravity and friction, in most cases) may suggest that involving students with 'actions' on 'other worlds' (for example, where friction does not exist) could help them to enlarge their experiences and possibly improve/modify their knowledge. The use of computer-games (like those described in Chapter 3, section 3.3), particularly when involving students in a 'non-frictional' environment may be a promising undertaking (for further arguments on this issue see diSessa, 1986). Research to investigate this issue seems to be, therefore, an worthwile investment.

(v) The 'dramatic' situation suggested by this research that physics teaching, at least up to the end of its compulsory level, does not change students' previous notions very much, seems to deserve also further investigation which should be centred on the question, what does science teaching really do to students?

My final comment about the report of this study is reflected by the following quotation with a small personal change (which is inserted, in brackets, in the quotation):

> 'In science one (...) is never in total command of the facts, and a scientist who waits until he knows everything before he says anything is like the man who will not make a decision until he has all the facts. One never has all the facts, the scientist's knowledge is always very limited, and he has to make (in this case, **to attempt to make**) the best with what he has got'.

(Bondi, 1964, pp 10)

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APPENDIX I

AN EXAMPLE OF EACH VERSION OF THE QUESTIONNAIRE

The following pages contain the versions of the questionnaire used in the Survey (i.e. QI.1, QI.2 and Q.II). The first, including English (QI.1) and Portuguese (QI.2) versions, being those used in study 1. The second (QII, in Portuguese) is the version used in study 2.

You are going to see six pictures of everyday events. In all of them there is an object (ball or tree) in different positions of its motion .

In any situation there may be no forces acting on the object , one force, or several forces.

For each situation there is a 'compass' showing possible (approximate) directions of forces acting on the object . Each 'compass' direction has a numbered box . The numbers of the boxes are also given on the top of each 'compass' .

Write by the numbers a name for the force which you think exists in the direction of each box .

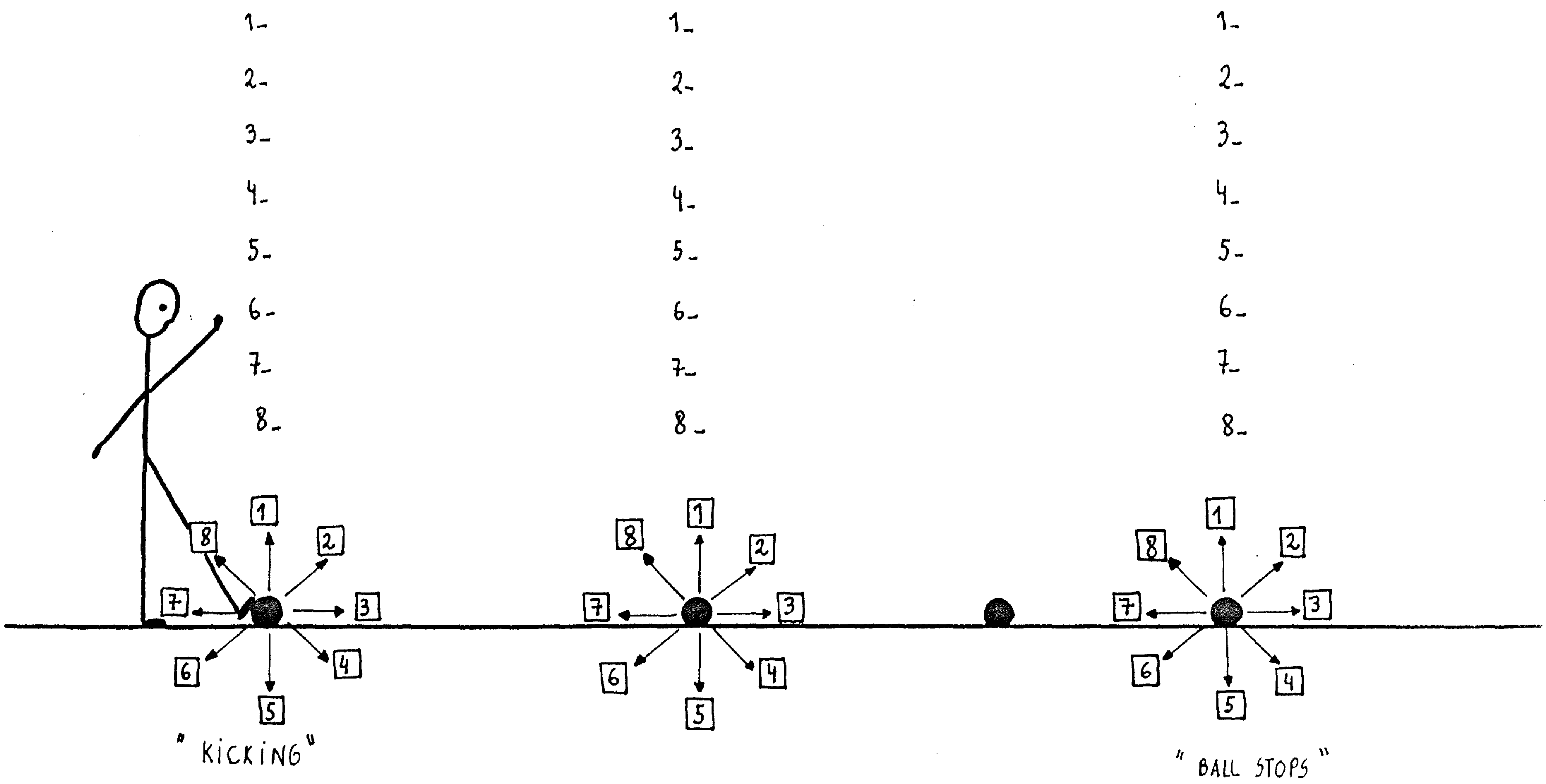
If there is no force in any direction , put "X" .

If you are not sure if there is a force or not in any direction , put "?F".

If you think there is a force but you do not know what to call it, put "? N ".

QI.1

A BALL SLOWING DOWN UNTIL A STOP AFTER IT HAS BEEN KICKED



FREE ROLLING OF A BALL DOWN AND UP ON A SLOPE

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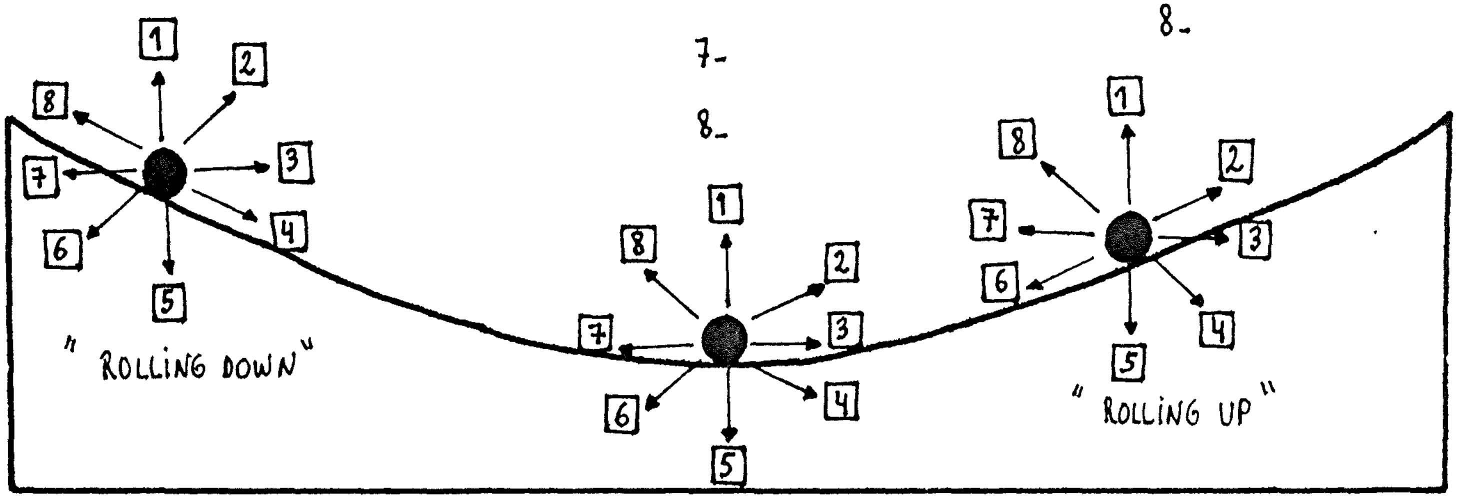

A BALL ROLLING OFF THE EDGE OF A TABLE

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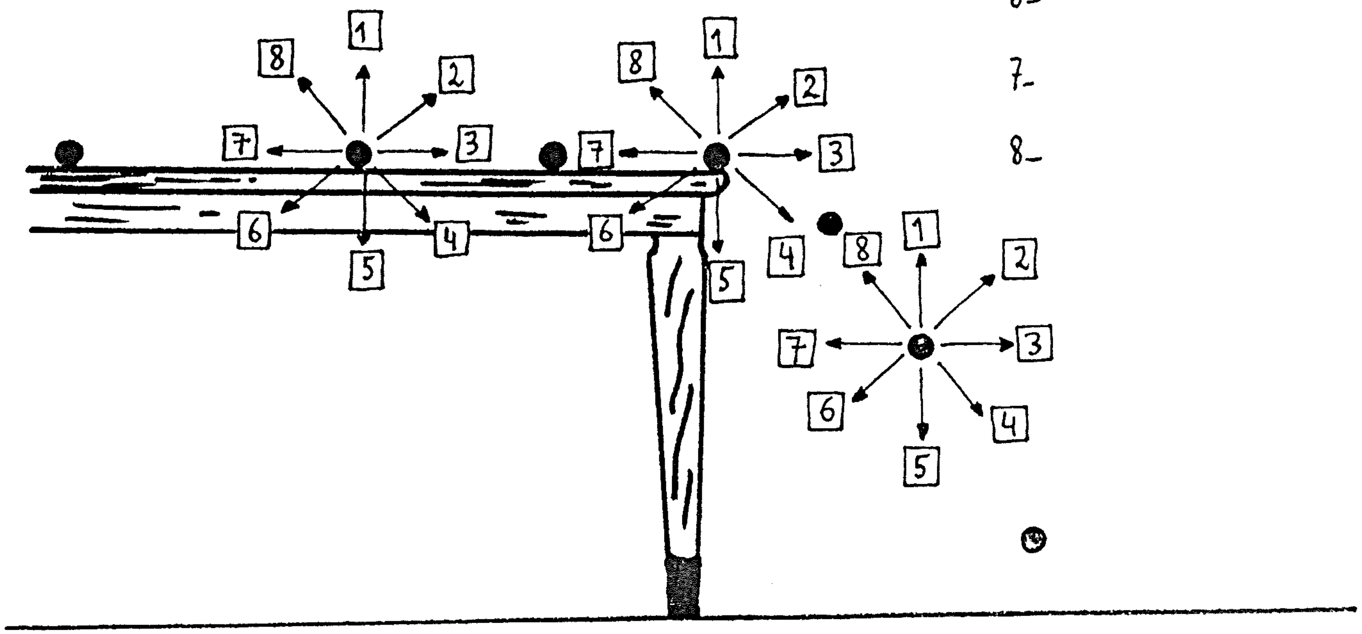

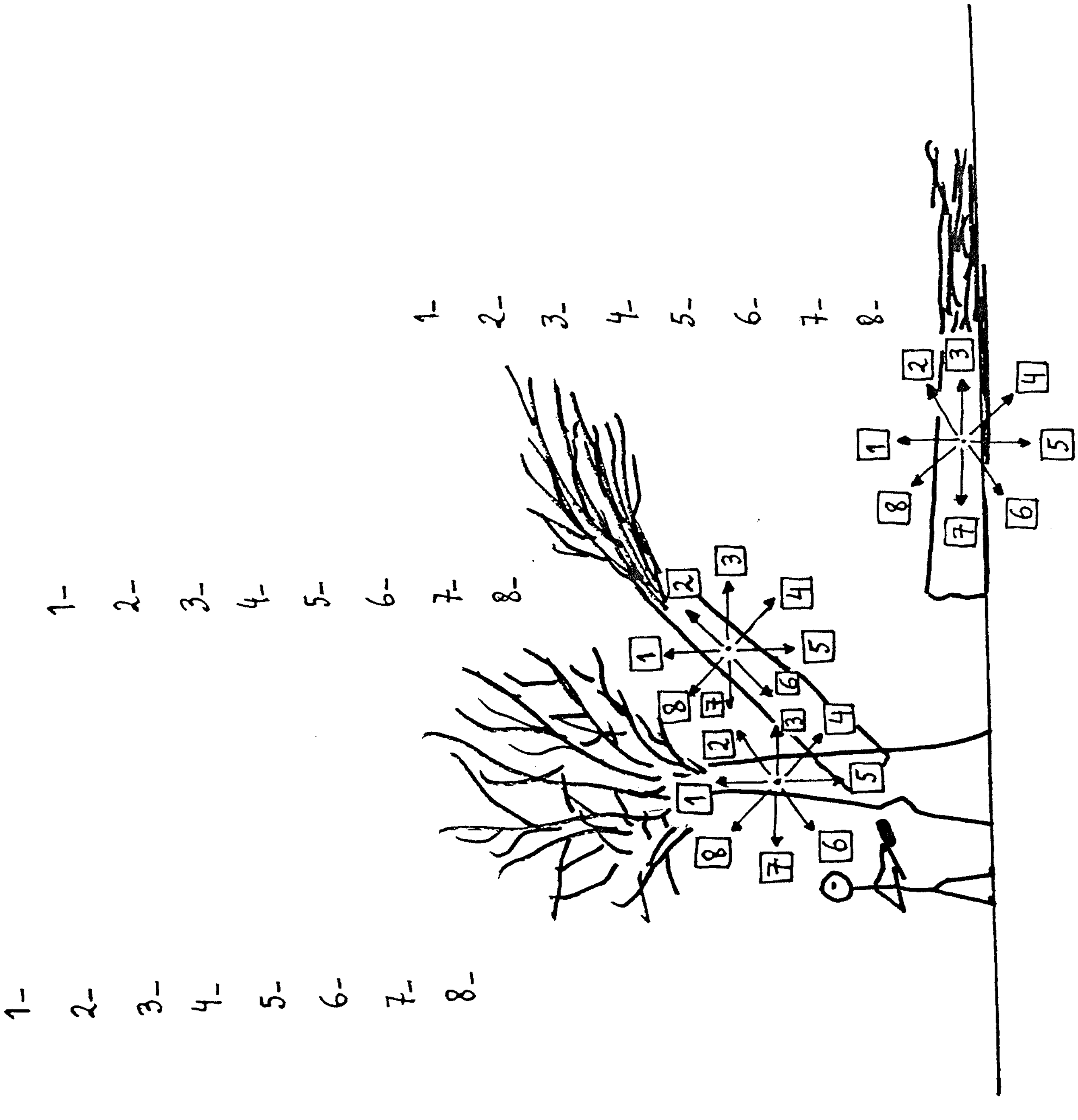
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A CANNON BALL BEING FIRED FROM A CANNON

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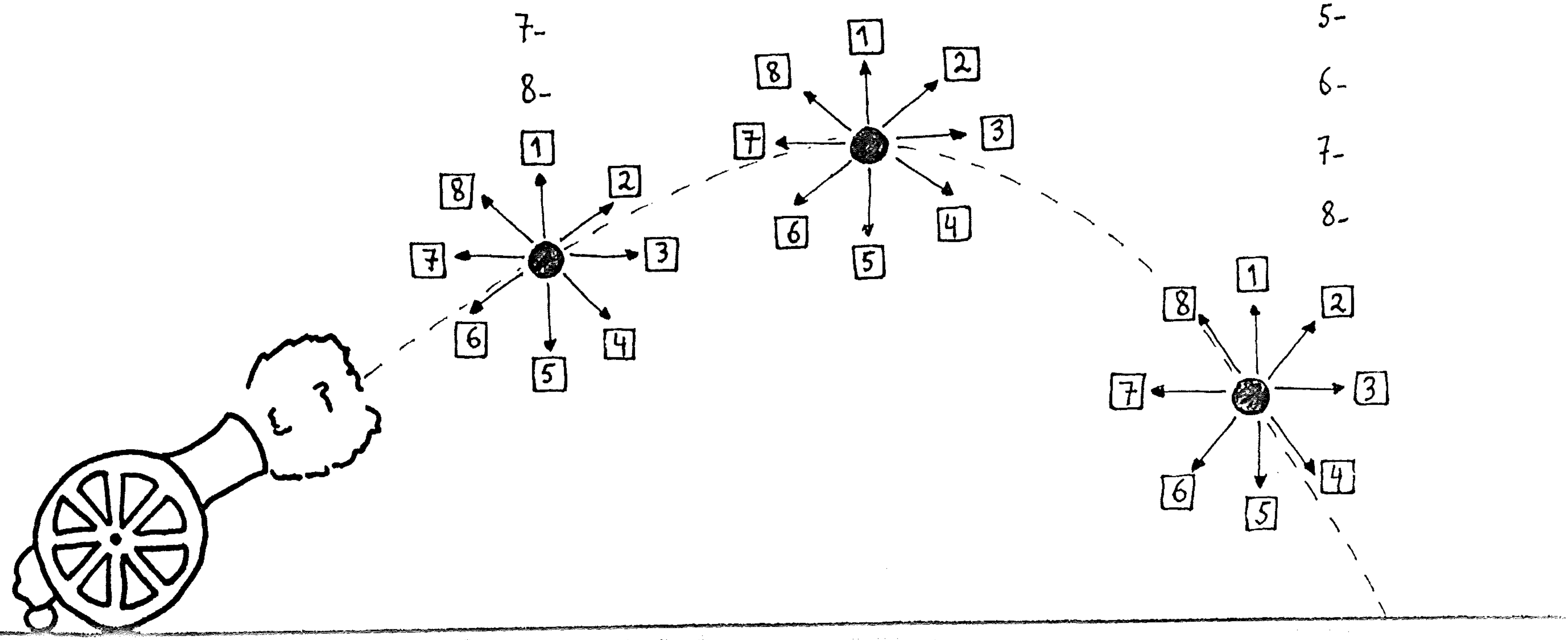
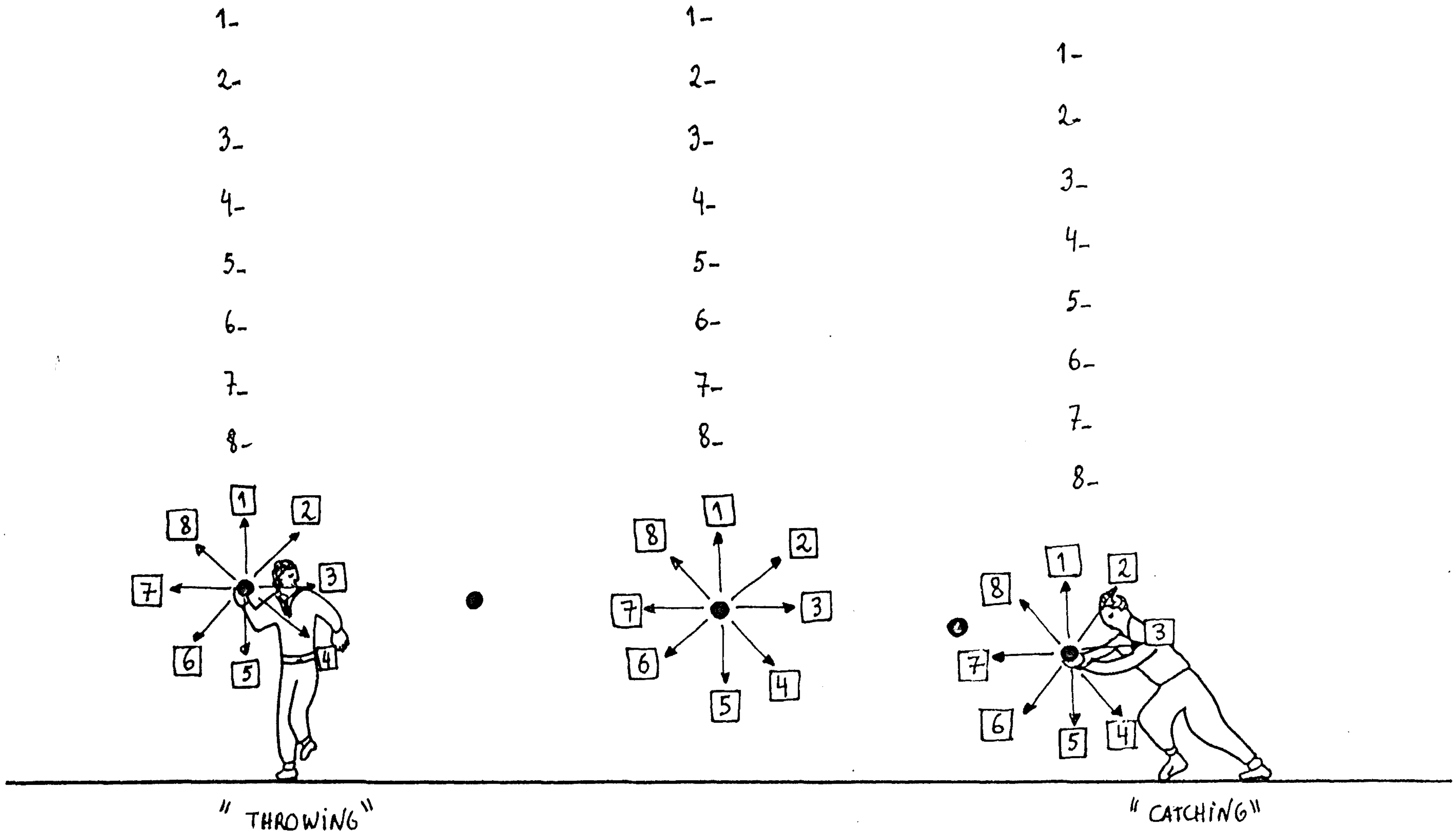
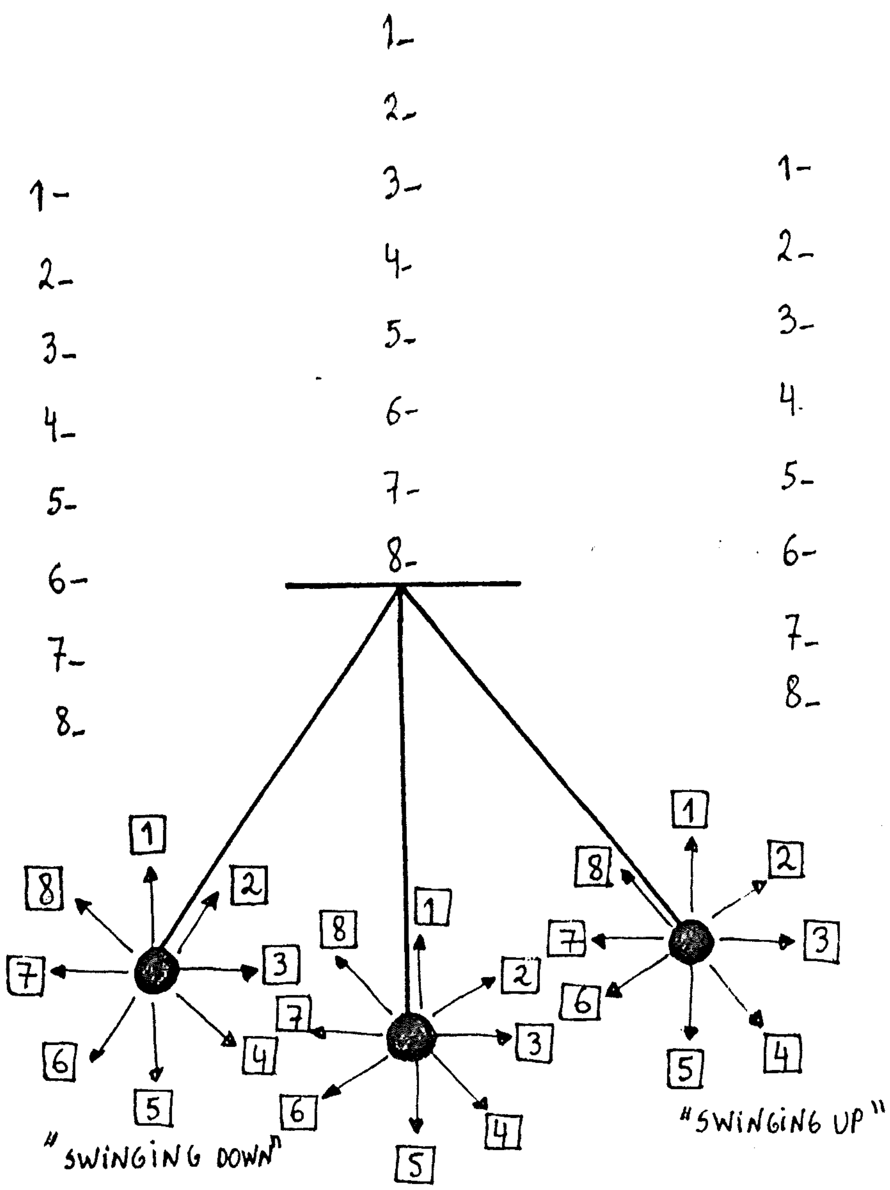


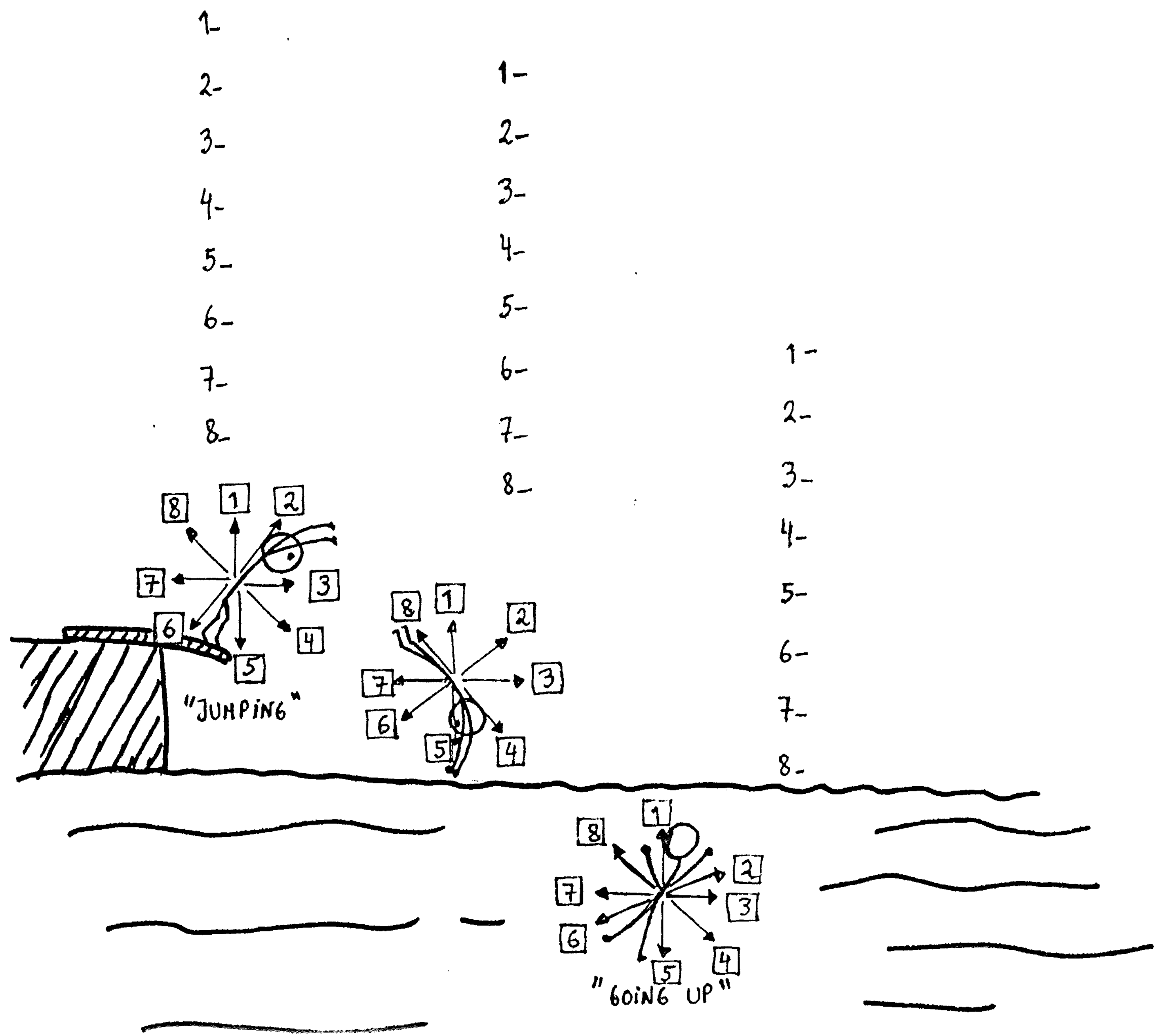
A BALL IS THROWN AND CAUGHT



A BALL SWINGING



DIVING INTO A POOL



NOME: ______________________________

IDADE: __________

SEXO: __________

ESCOLA: ______________________________

TURMA: __________

O questionário a que vais agora responder destina-se a um trabalho que têm por objectivo investigar ideias que as pessoas têm sobre ***FORÇAS***.

Este questionário ***NÃO É UM TESTE***. Com ele não se pretende saber se aprendeste correcta ou incorrectamente o que te foi ensinado; mas sim saber as ***TUAS IDEIAS*** sobre as ***FORÇAS*** que existem nas diferentes situações que te vão ser apresentadas. Tenta pois responder discontraídamente, e não hesites em exprimir as ***TUAS IDEIAS***.

Algumas indicações sobre a maneira de responder são dadas a seguir.

Nas folhas que se seguem estão representadas algumas situações comuns, referentes a movimentos de um objectivo ou de uma pessoa.

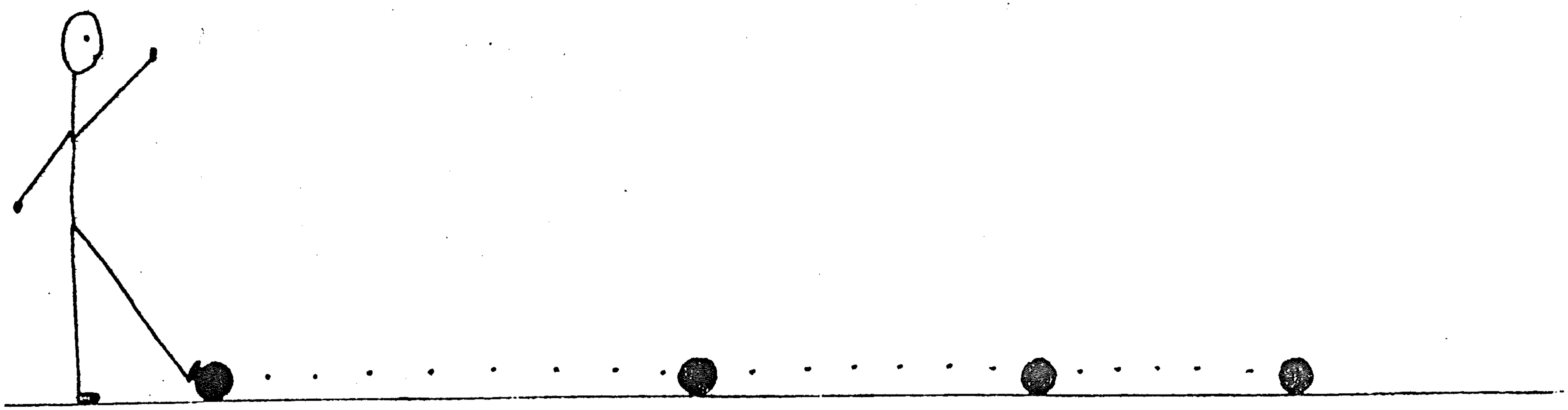
Relativamente a cada situação tens duas folhas:

- na primeira tens um desenho que representa esquemàticamente a situação. ***NADA TENS QUE RESPONDER***

- na segunda representa-se o objecto (ou pessoa) em vários instantes do seu percurso e também algumas direcções e sentidos (aproximadas) de forças a que o objecto (ou pessoa) pode estar sujeito. Estas direcções e sentidos estão indicadas por números: uma para cada sentido.

  Para cada instante ***INDICA SE HÁ ALGUMA FORÇA (OU FORÇAS) ESCREVENDO O SEU NOME JUNTO DO NÚMERO QUE REFERE O SENTIDO DA FORÇA***. Se não tens a certeza se existe ou não uma força num dado sentido escreve um ***F*** junto ao número correspondente. Se pensas que existe uma força num dado sentido mas não sabes que nome lhe dar, escreve um ***N*** junto ao número correspondente.

UM HOMEM CHUTA UMA BOLA E DEPOIS DE ALGUM TEMPO ELA PARA



UM HOMEM CHUTA UMA BOLA E DEPOIS DE ALGUM TEMPO ELA PARA

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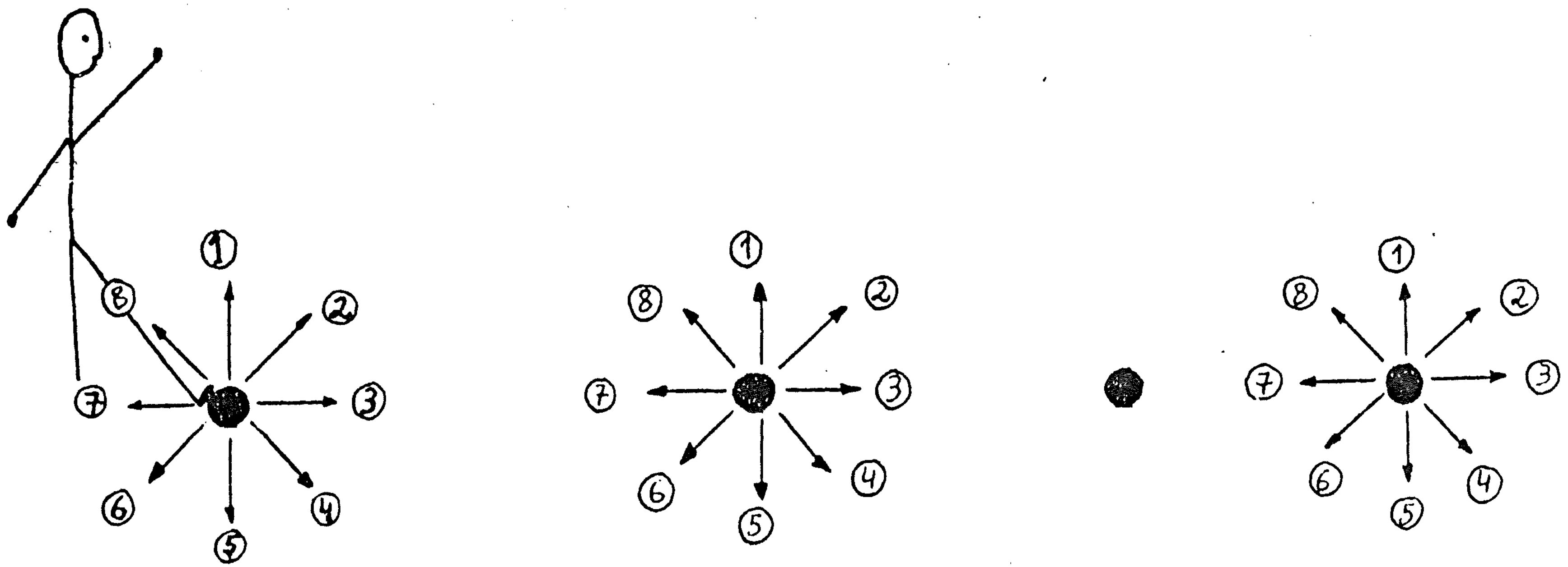
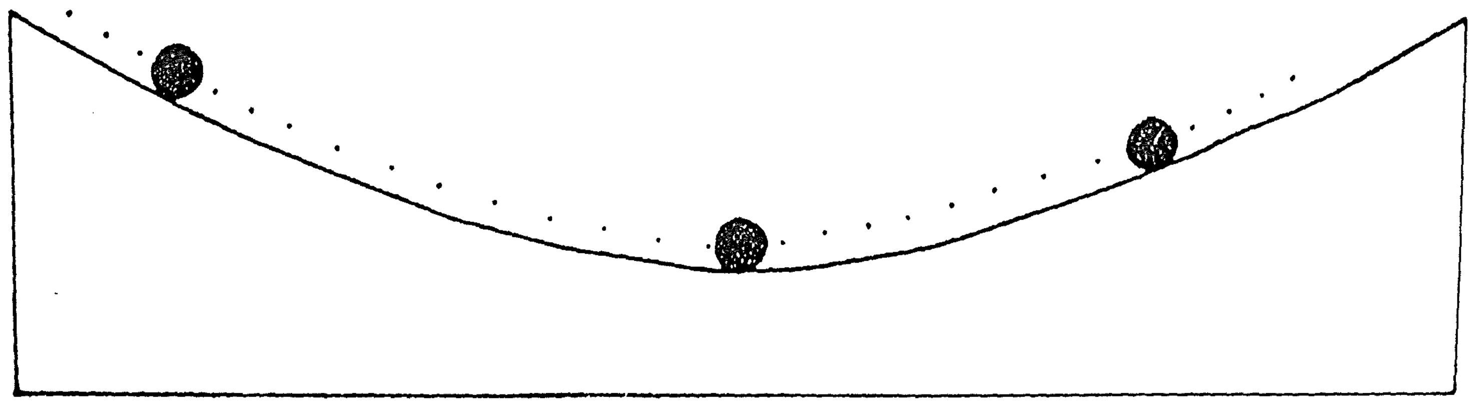


UMA BOLA DESCE LIVREMENTE UMA SUPERFICIE CURVA E A SEGUIR SOBE-A



UMA BOLA DESCE LIVREMENTE UMA SUPERFICIE CURVA E A SEGUIR SOBE-A

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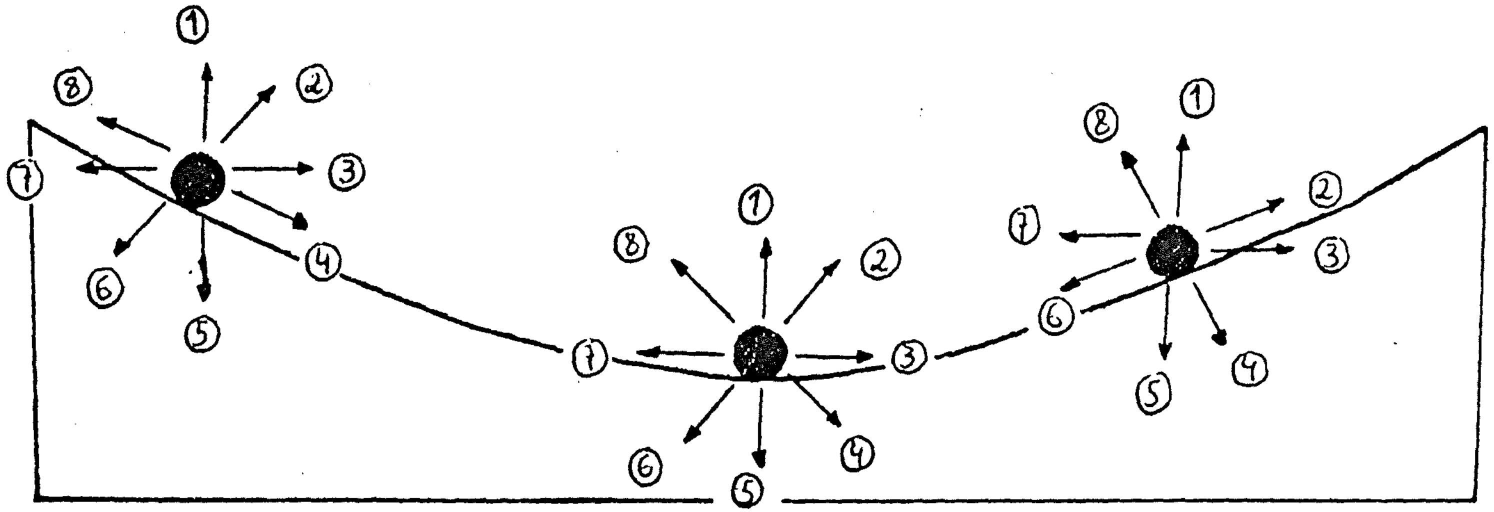
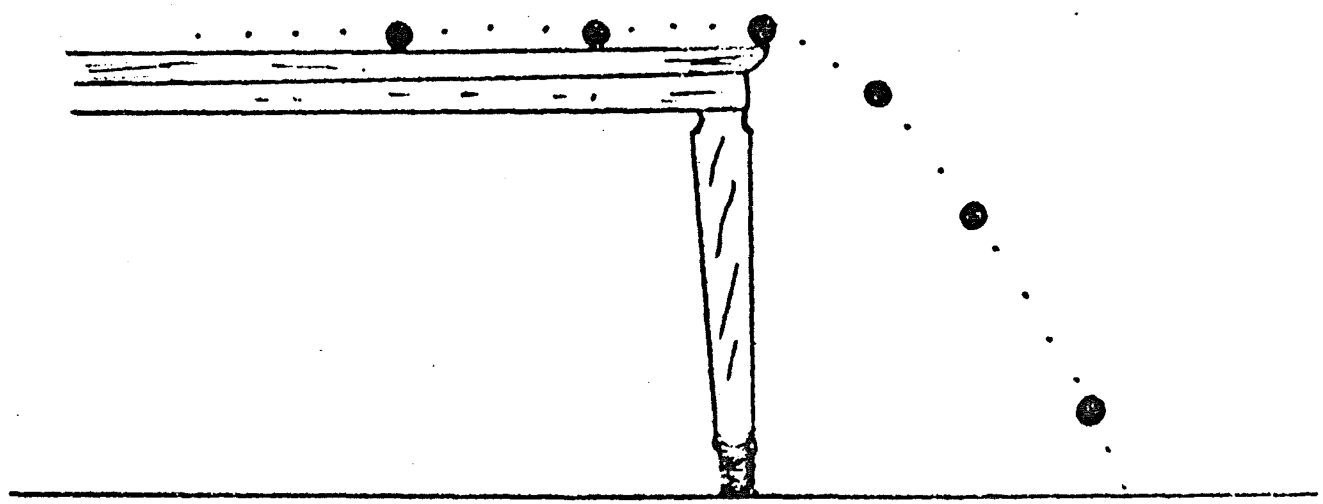


UMA BOLA DESLIZA SOBRE UMA MESA E CAI



UMA BOLA DESLIZA SOBRE UMA MESA E CAI

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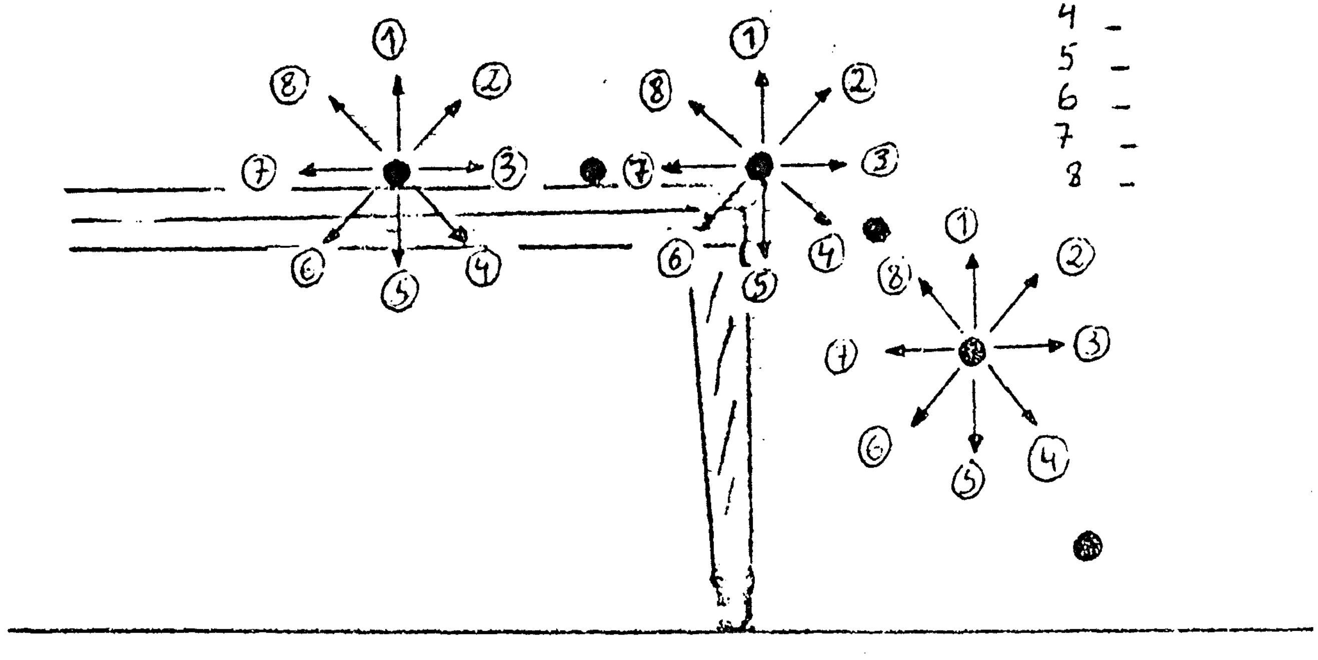
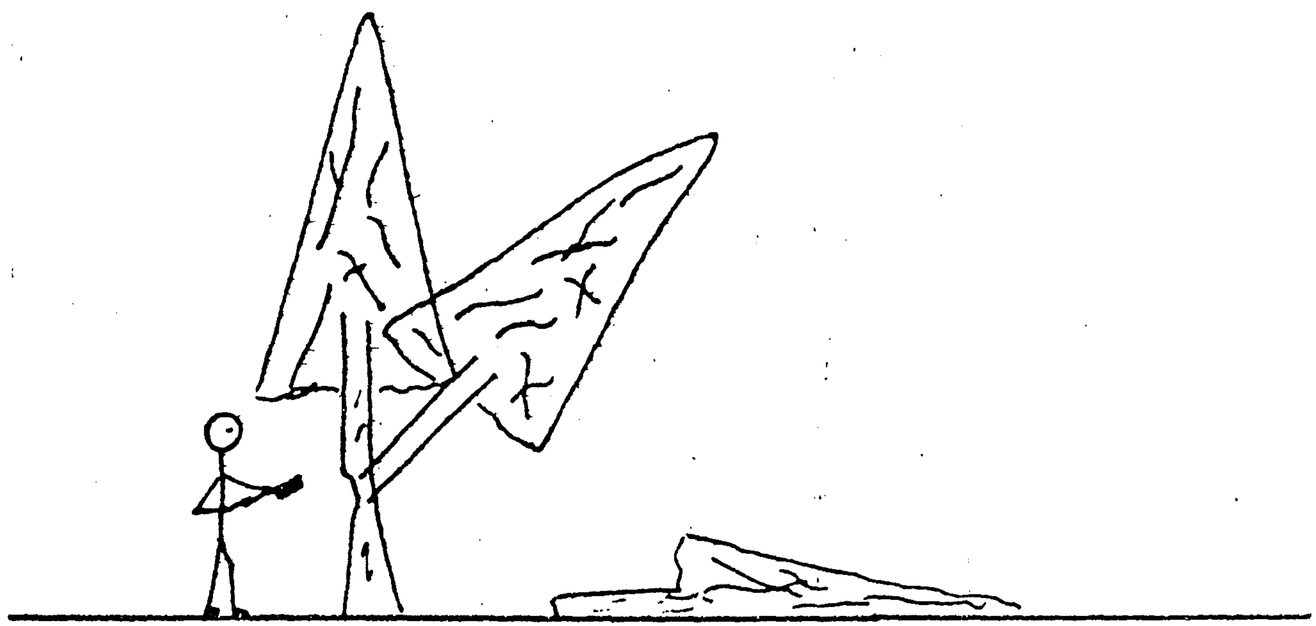
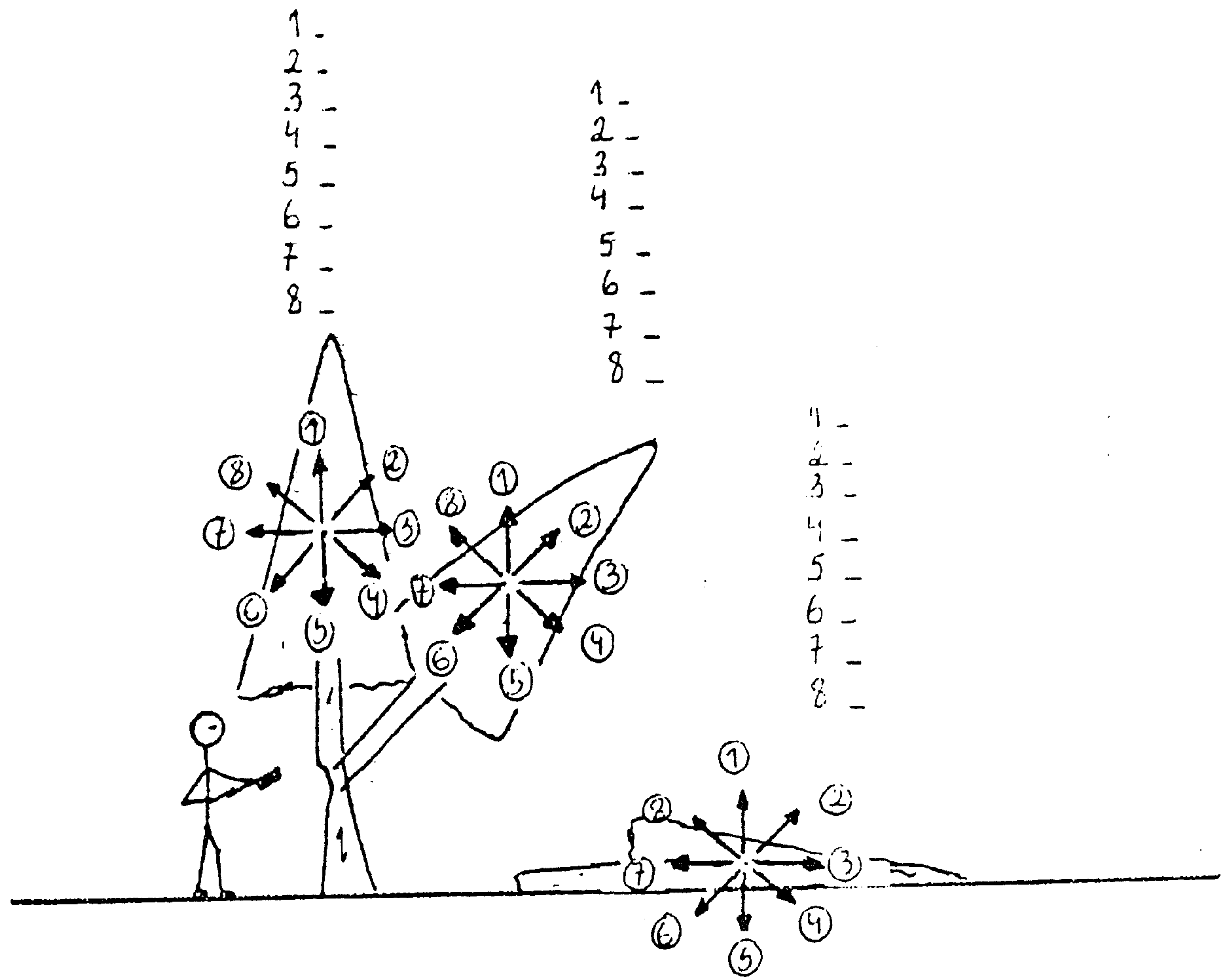


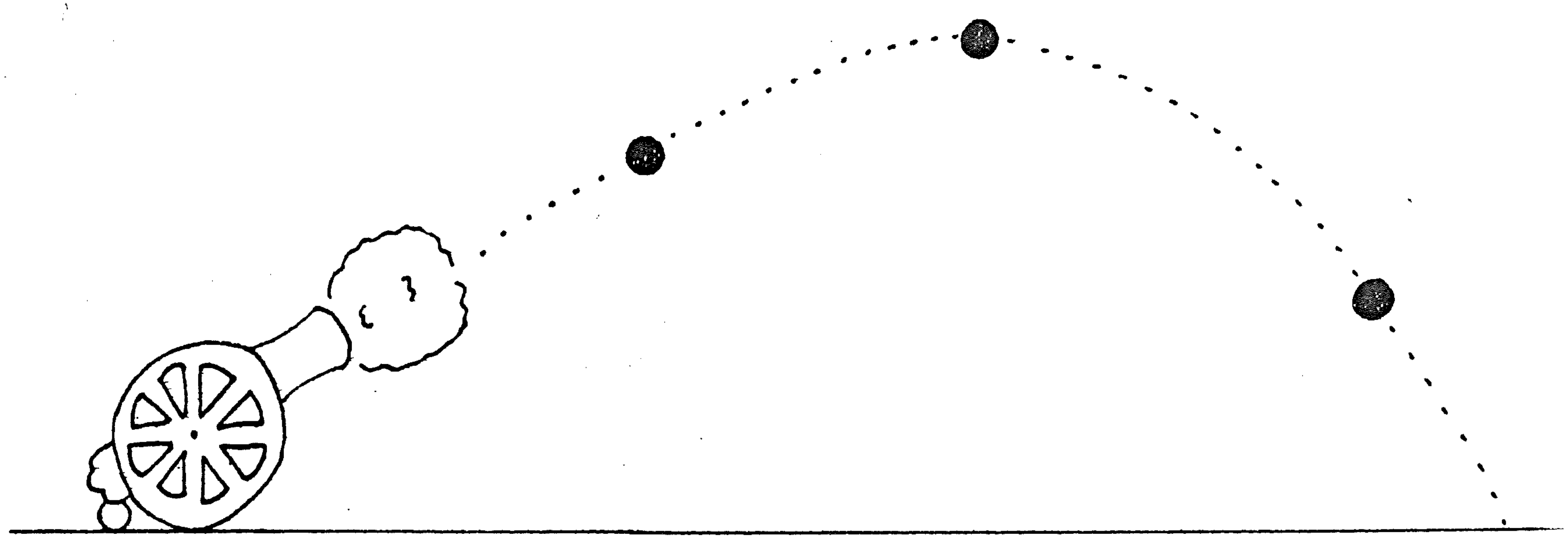
UM HOMEM CORTA UMA ÁRVORE E ELA CAI



UM HOMEM CORTA UMA ÁRVORE E ELA CAI



PERCURSO DE UMA BOLA QUE É DISPARADA DE UM CANHÃO



PERCURSO DE UMA BOLA QUE É DISPARADA DE UM CANHÃO

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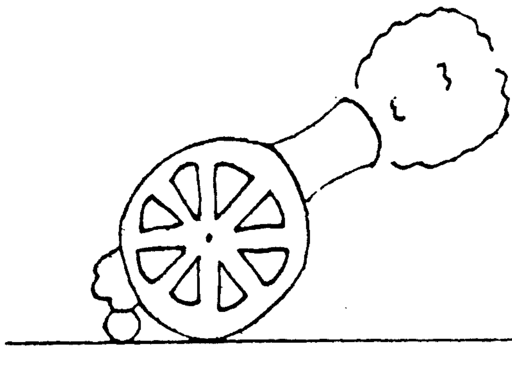
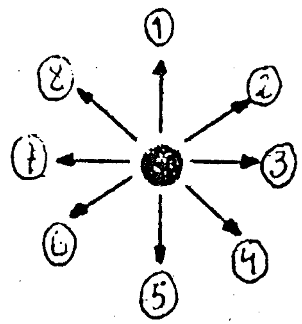
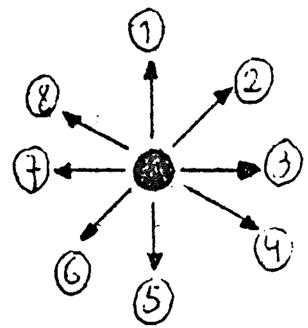
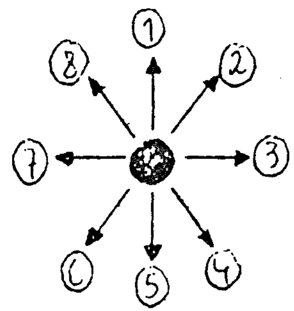
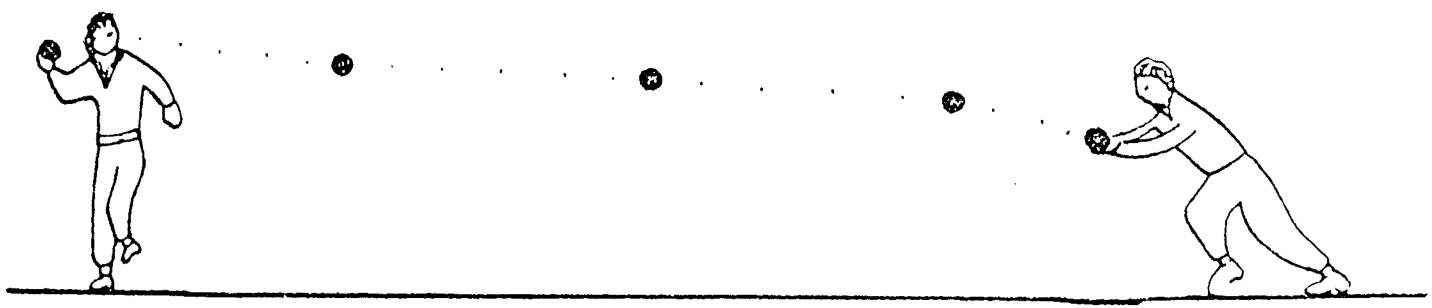








UM HOMEM ATIRA UMA BOLA E OUTRO APANHA-A



UM HOMEM ATIRA UMA BOLA E OUTRO APANHA-A

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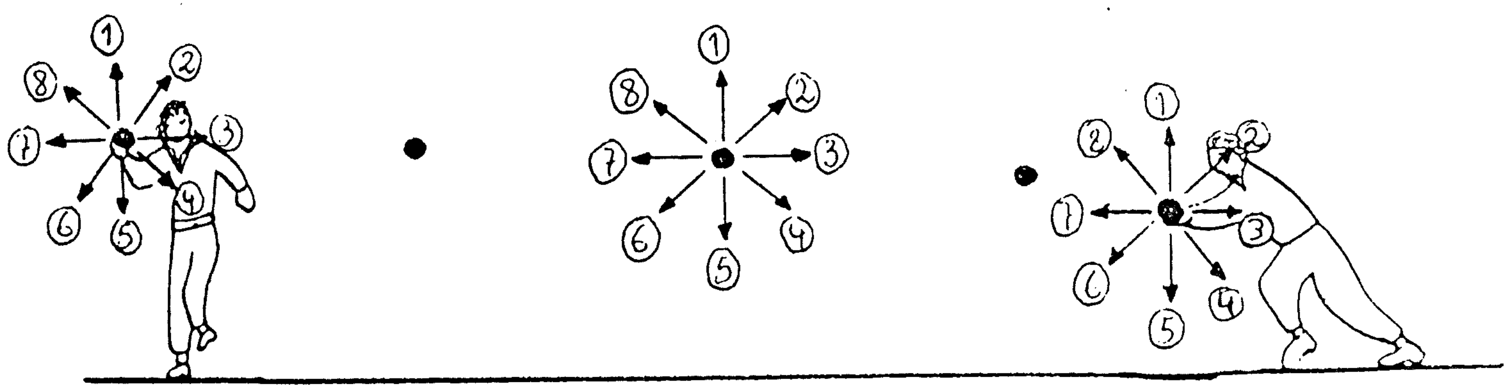
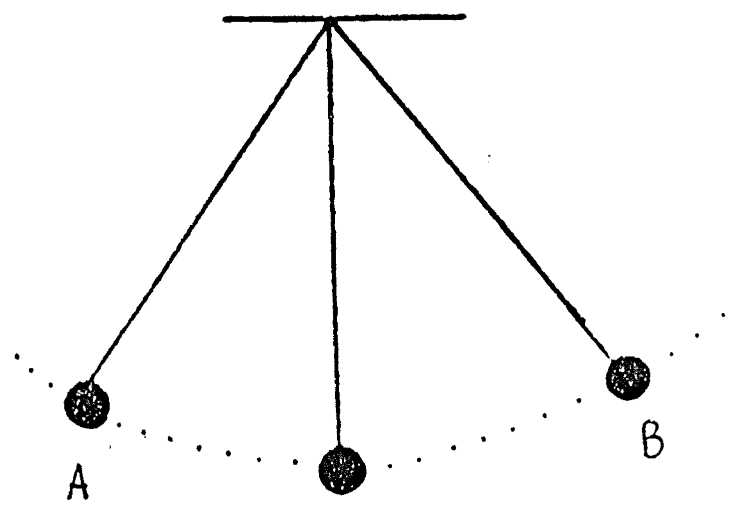
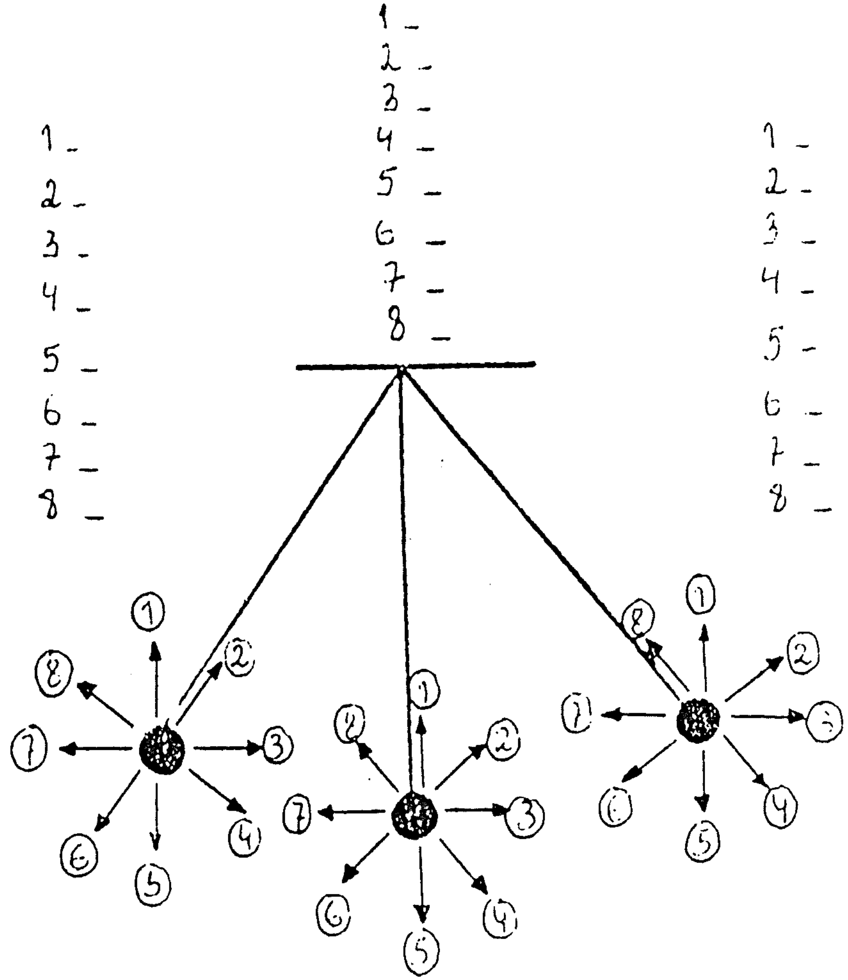


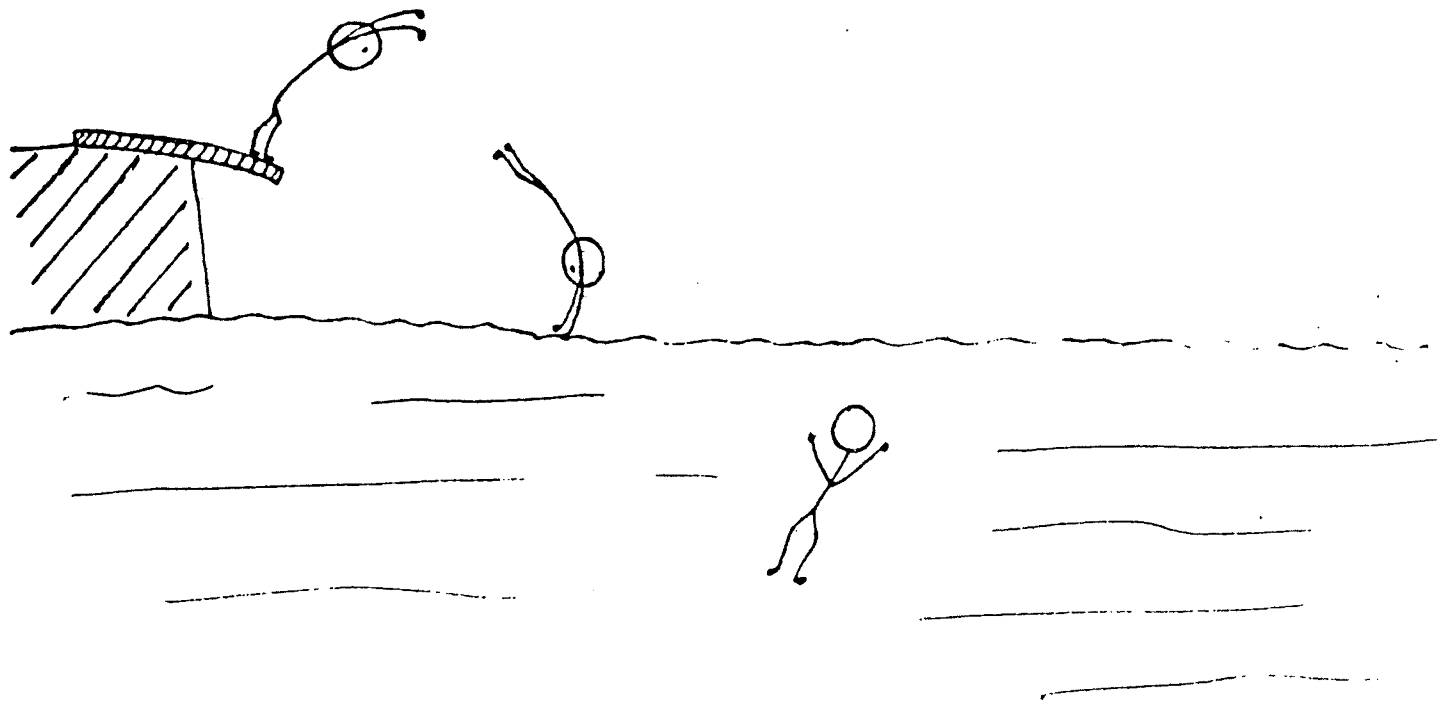
UMA BOLA SUSPENSA POR UM FIO, OSCILA DE *A* PARA *B*



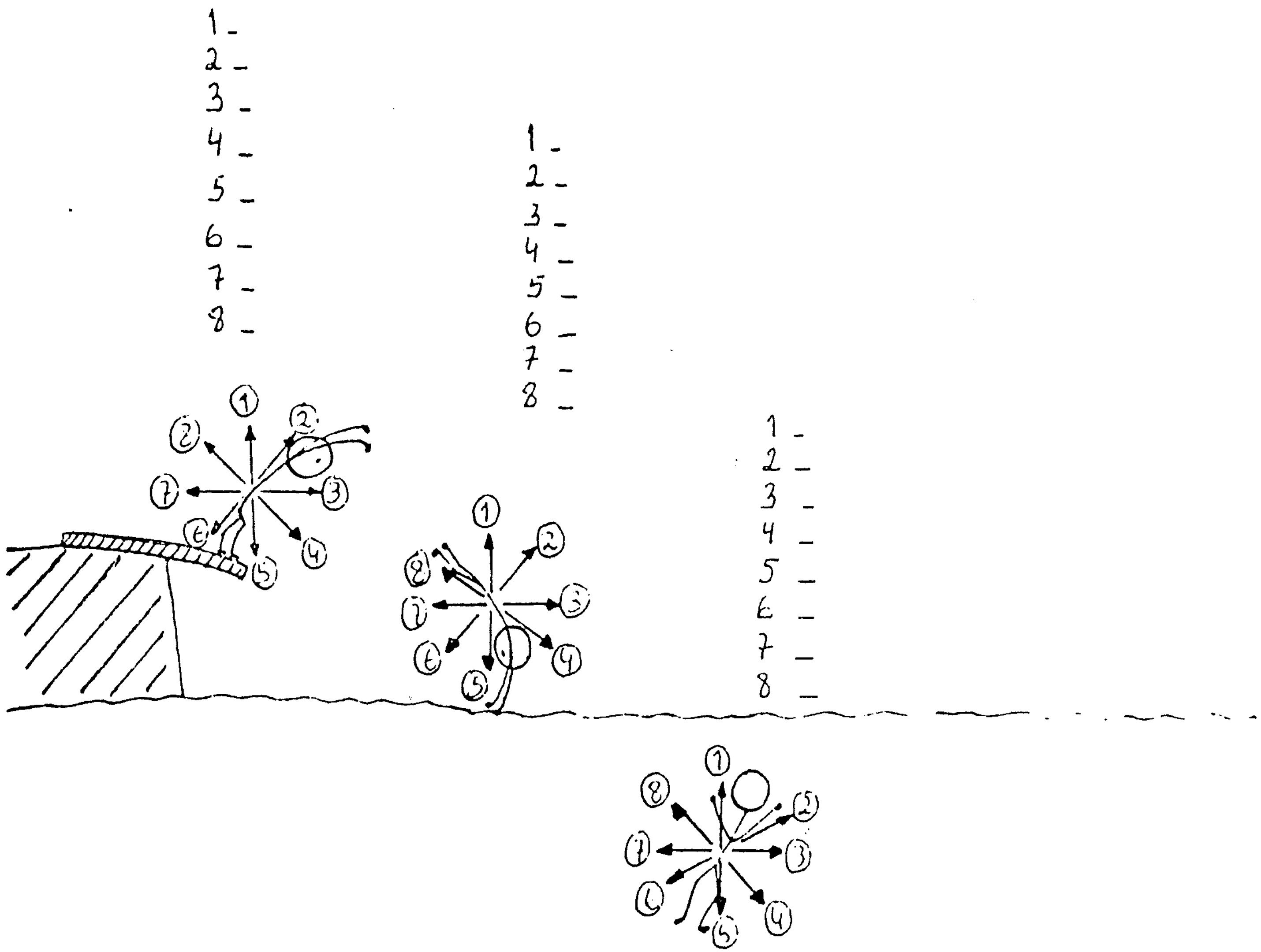
UMA BOLA SUSPENSA POR UM FIO, OSCILA DE A PARA B



UM HOMEM SALTA DE UMA PISCINA, MERGULHA E VOLTA PARA A SUPERFÍCIE



UM HOMEM SALTA DE UMA PISCINA, MERGULHA E VOLTA PARA A SUPERFÍCIE



NOME: ______________________________

IDADE: ______________

SEXO: ______________

ESCOLA: ______________________________

TURMA: ______________

O questionário a que vais agora responder destina-se a um trabalho que têm por objectivo investigar ideias que as pessoas tem sobre **FORÇAS** .

Este questionário **NÃO É UM TESTE** . Com ele não se pretende saber se aprendeste correcta ou incorrectamente o que te foi ensinado; mas sim saber as **TUAS IDEIAS** sobre as **FORÇAS** que existem nas diferentes situações que te vão ser apresentadas. Tenta pois responder discontraídamente, e não hesites em exprimir as **TUAS IDEIAS**.

Algumas indicações sobre a maneira de responder são dadas a seguir.

Nas folhas que se seguem estão representadas algumas situações comuns, referentes a movimentos de um objecto ou de uma pessoa.

Relativamente a cada situação tens quatro folhas:

- na primeira tens um desenho que representa esquemàticamente a situação. **NADA TENS QUE RESPONDER** .

- nas três seguintes representa-se o objecto(ou pessoa) num dado instante do seu percurso, assim como algumas direcções e sentidos (aproximadas) de forças a que o objecto(ou pessoa) pode estar sujeito. A cada uma destas direcções e sentidos corresponde um quadrado (☐) e um espaço assinalado por '-------'. **INDICA SE HÁ ALGUMA FORÇA (OU FORÇAS) E, CASO EXISTAM** , **DÁ A CADA UMA DELAS UM NOME** .Para isso ,

  - coloca em cada quadrado:

    [V] - se existe uma força nessa direcção e sentido

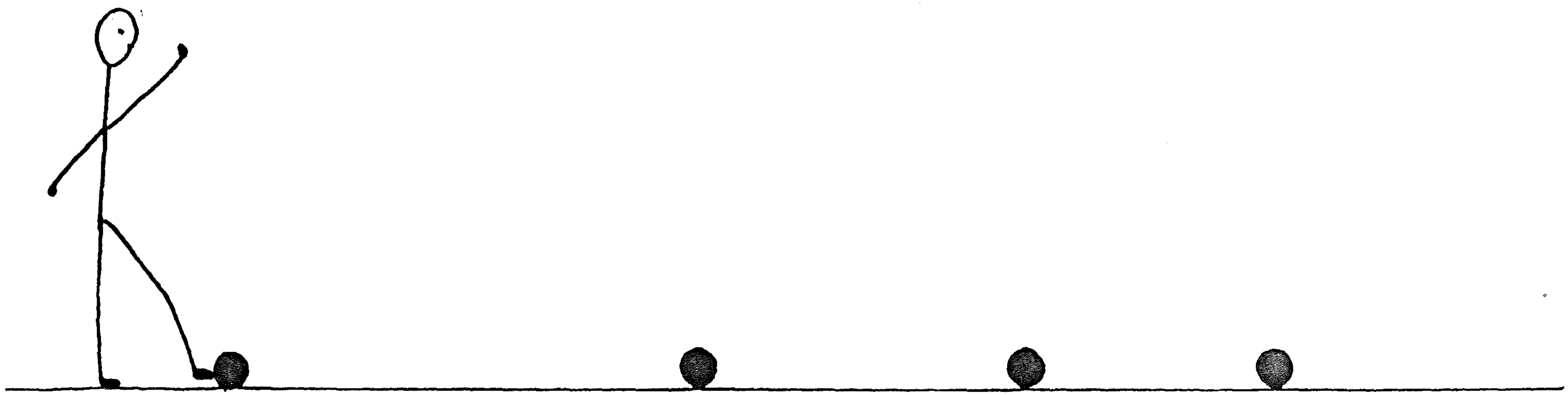
    [?] - se não tens a certeza se existe ou não uma força nessa direcção e sentido

    (ou deixa-o vazio se não existe força)

  - escreve um nome,no espaço assinalado por '------',para cada uma das forças que consideraste.

    (Ou deixa-o vazio , se não conseguires dar-lhe um nome)

UM HOMEM CHUTA UMA BOLA E DEPOIS DE ALGUM TEMPO ELA PARA



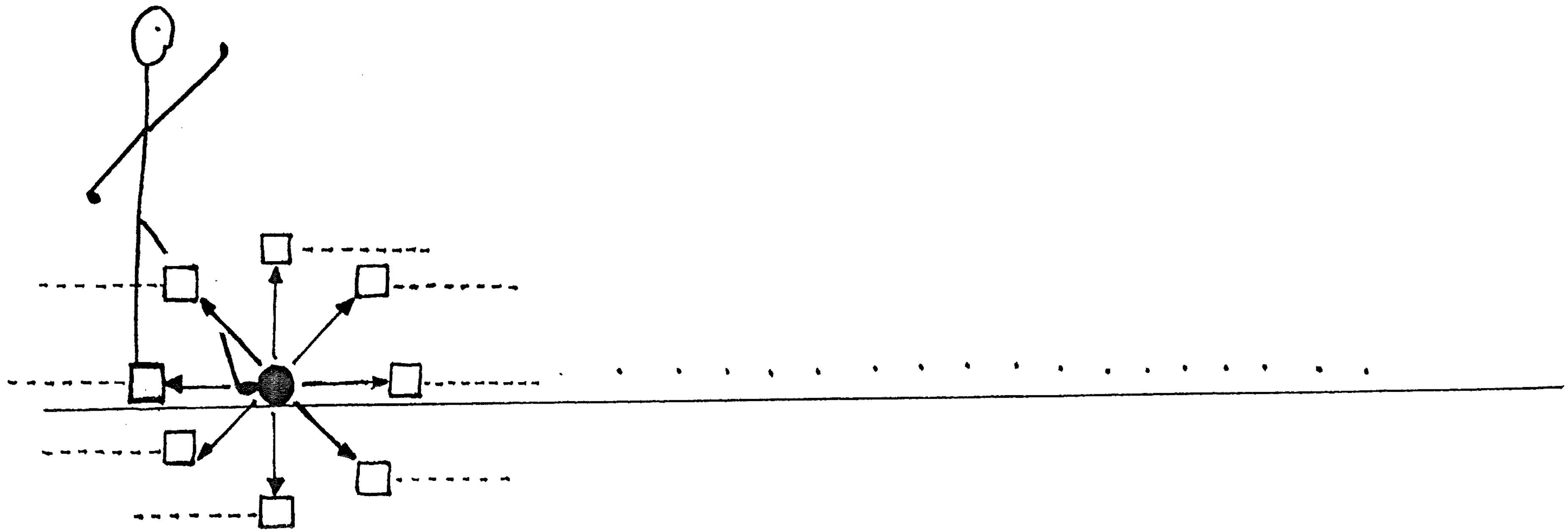
• COLOCA EM CADA QUADRADO:

[V] – se existe força

[?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

• ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
(ou deixa o espaço vazio se não consegues dar um nome à força)



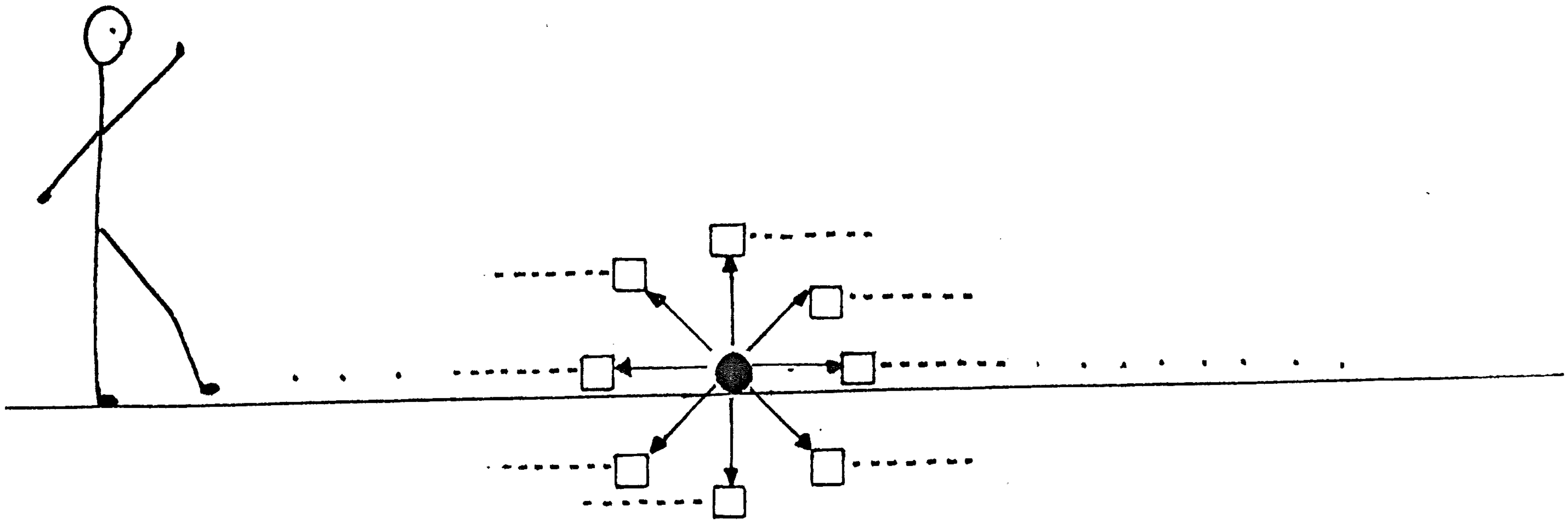
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



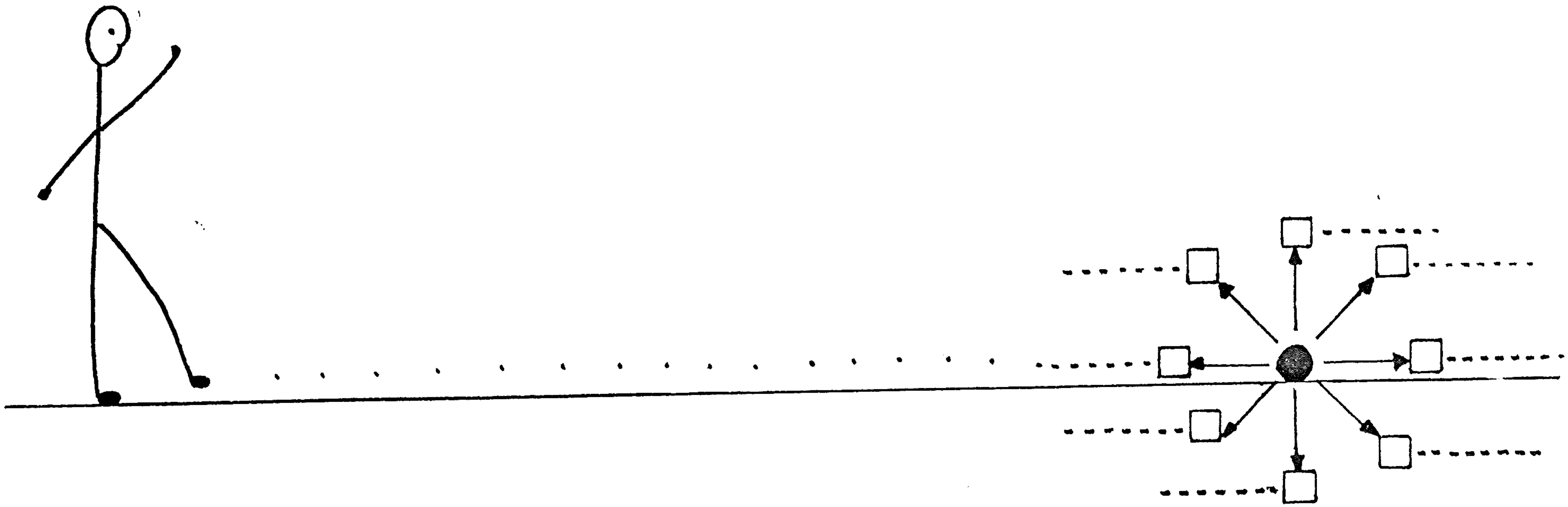
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

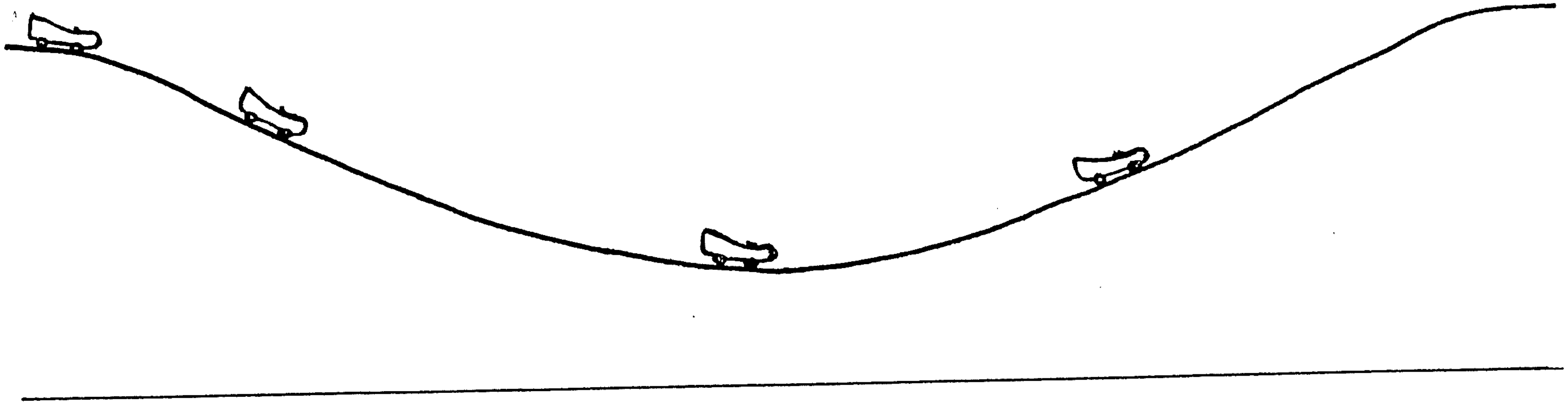
  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UM CARRO (SEM MOTOR) DESCE LIVREMENTE UMA PISTA E A SEGUIR SOBE-A



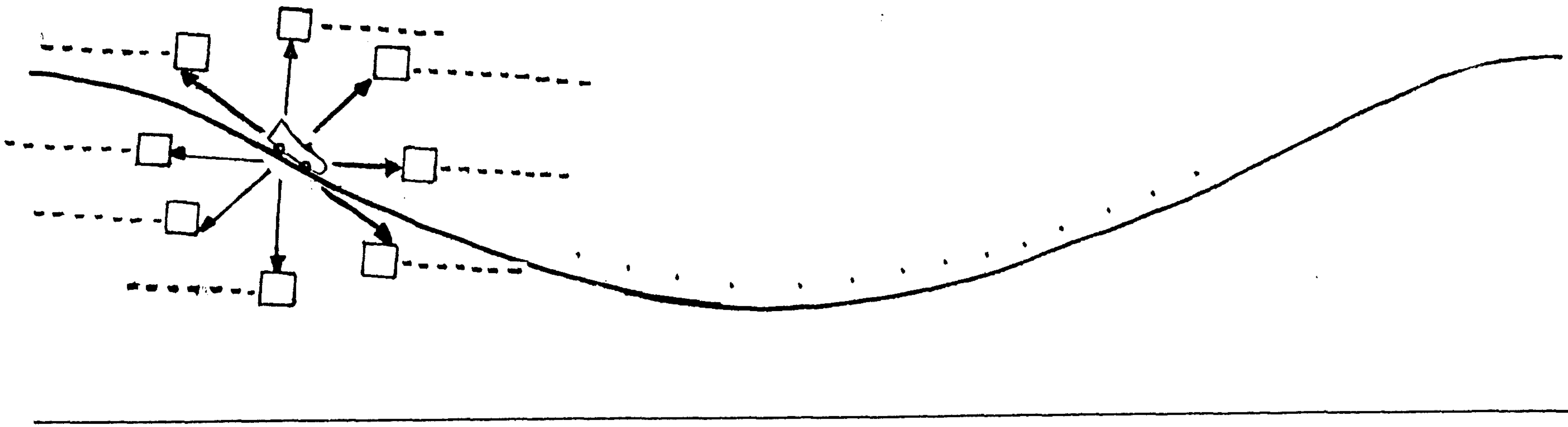
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



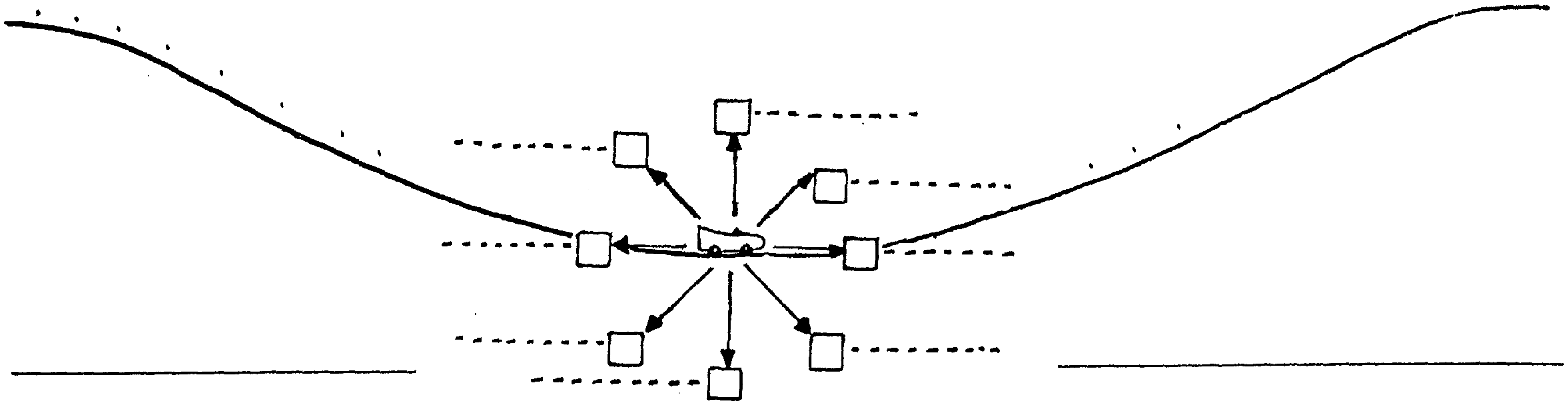
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



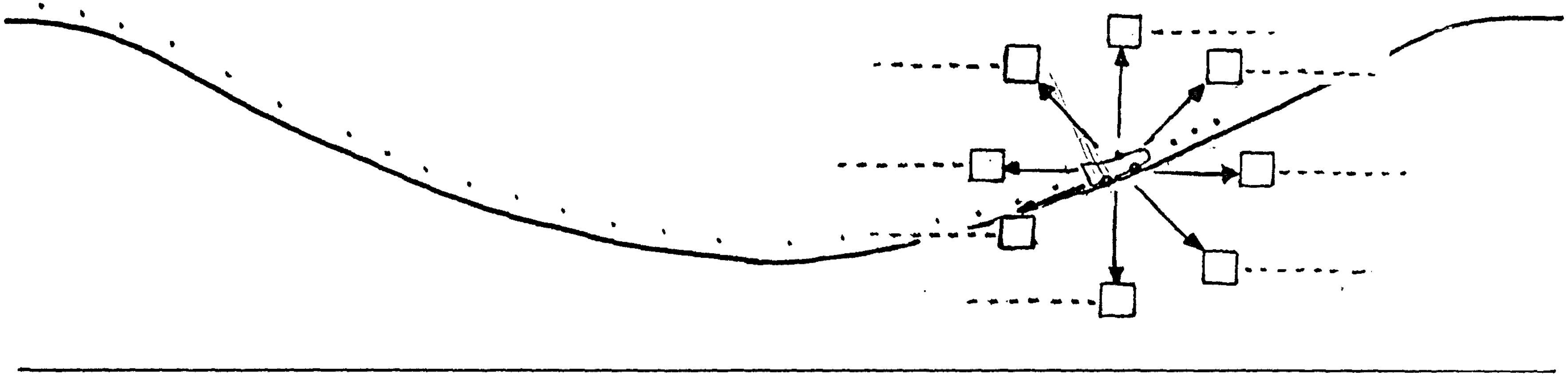
- COLOCA EM CADA QUADRADO:

  ☑ – se existe força

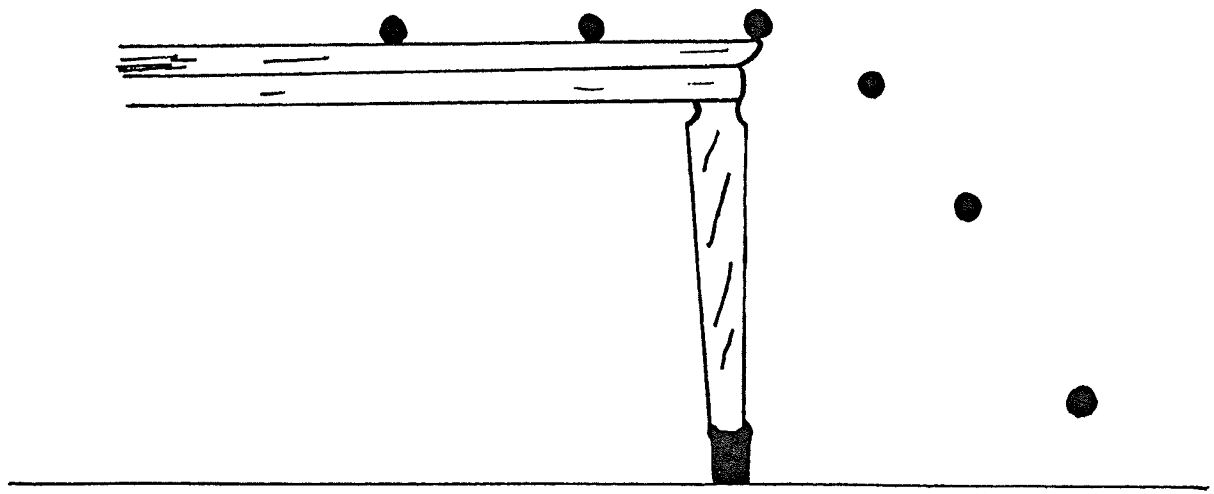
  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UMA BOLA ROLA SOBRE UMA MESA E CAI



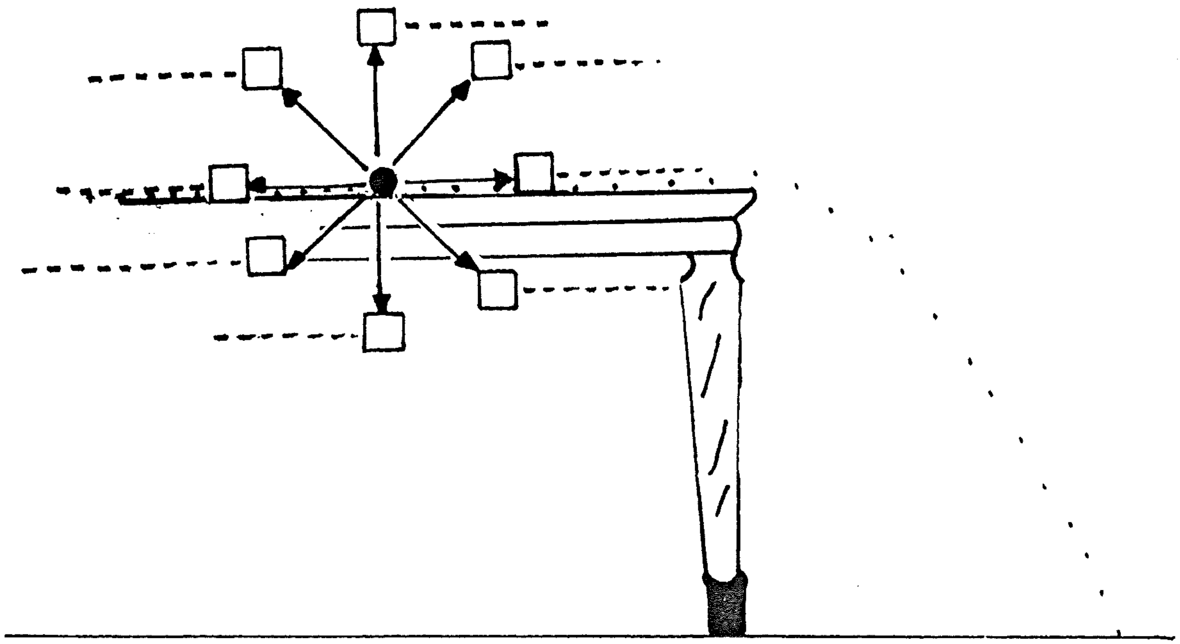
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



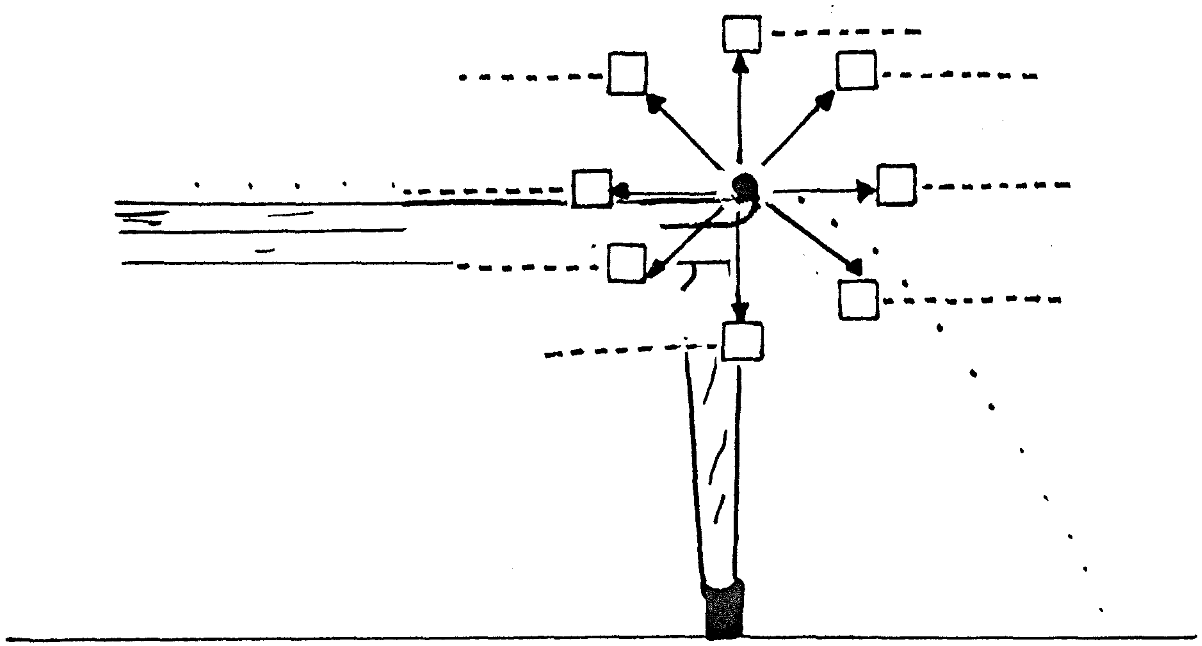
- COLOCA EM CADA QUADRADO:

  [V] – se existe força

  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



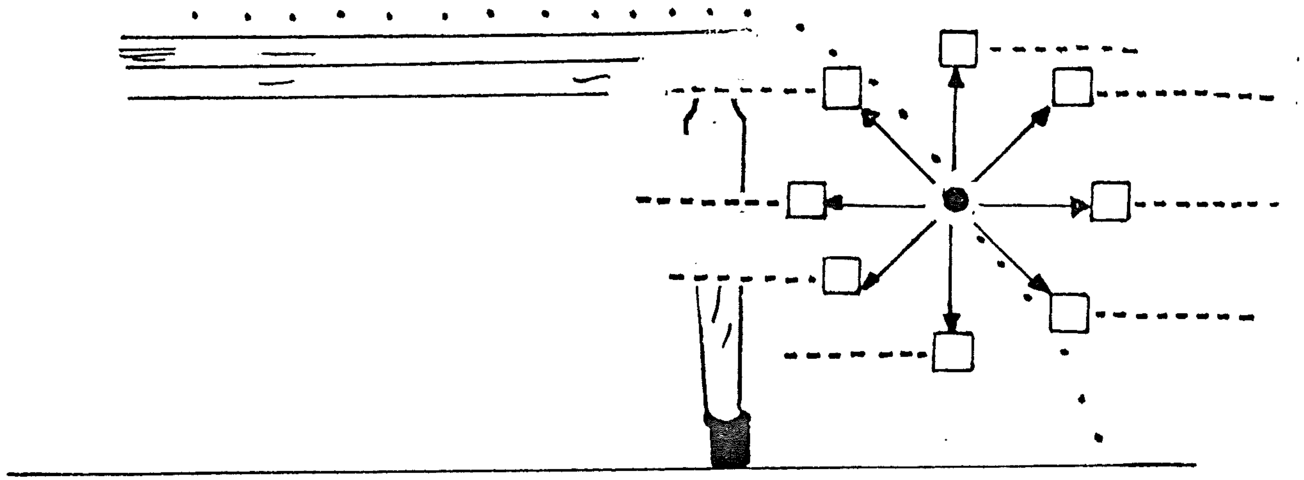
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

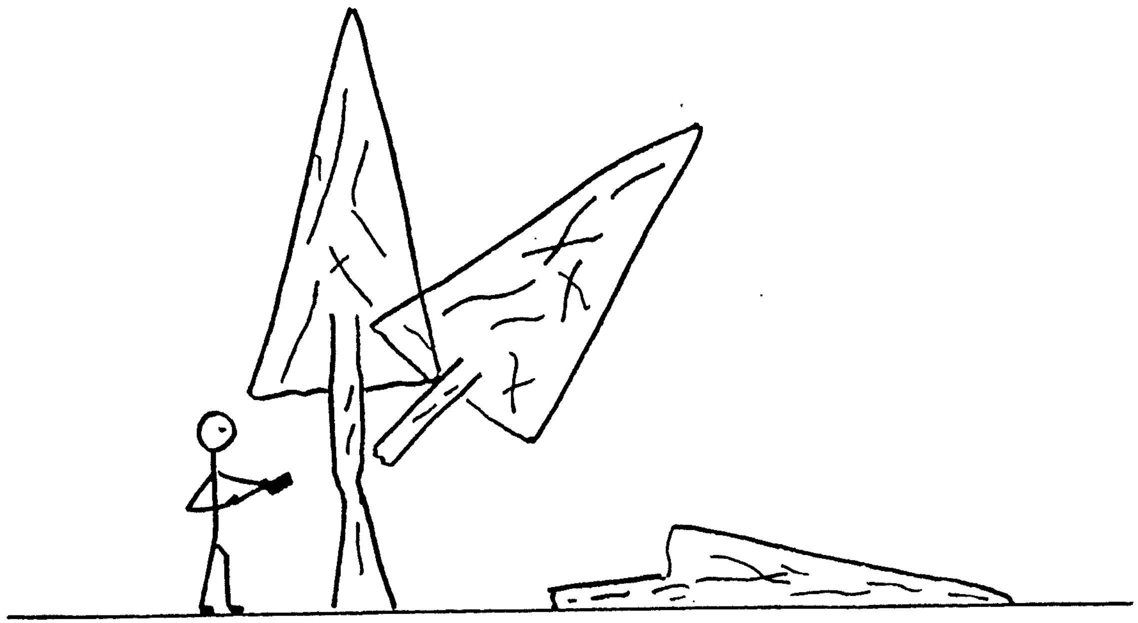
  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UM HOMEM CORTA UMA ÁRVORE E ELA CAI



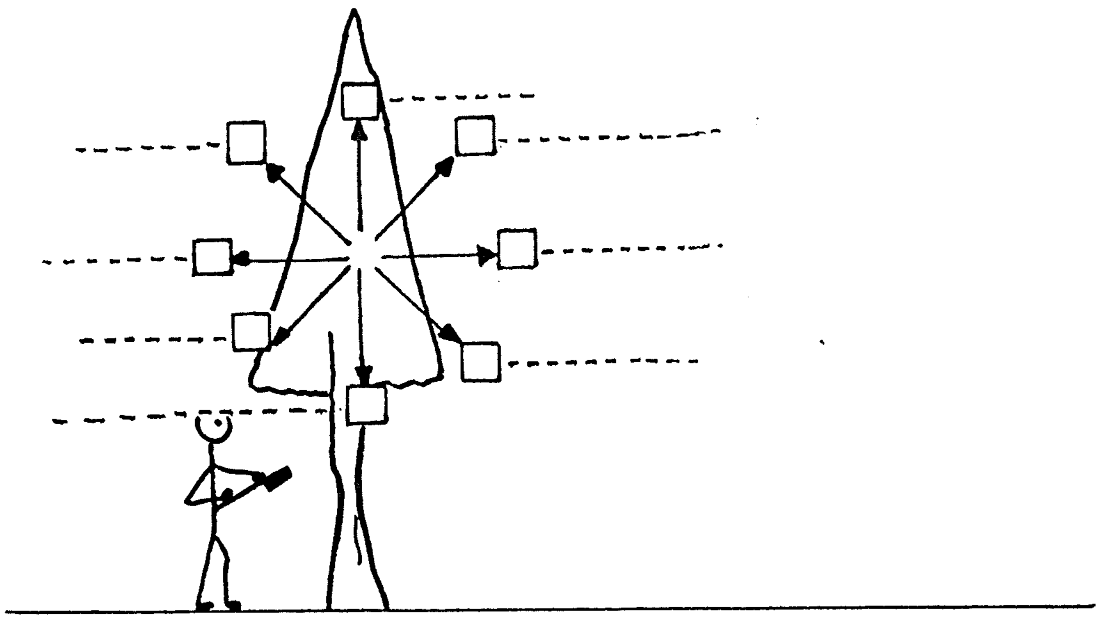
- COLOCA EM CADA QUADRADO:

  [V] – se existe força

  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



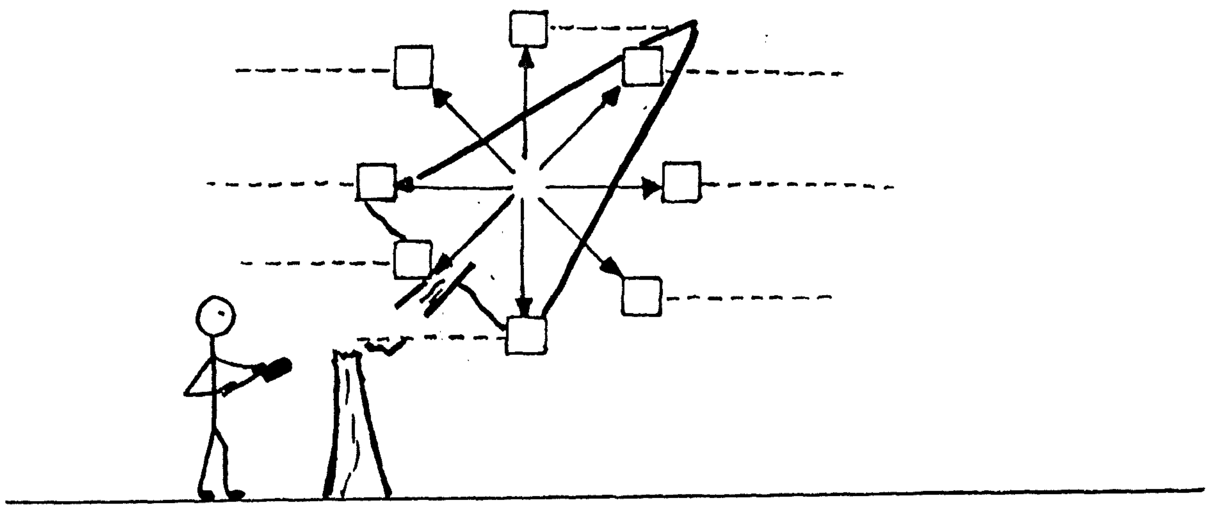
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



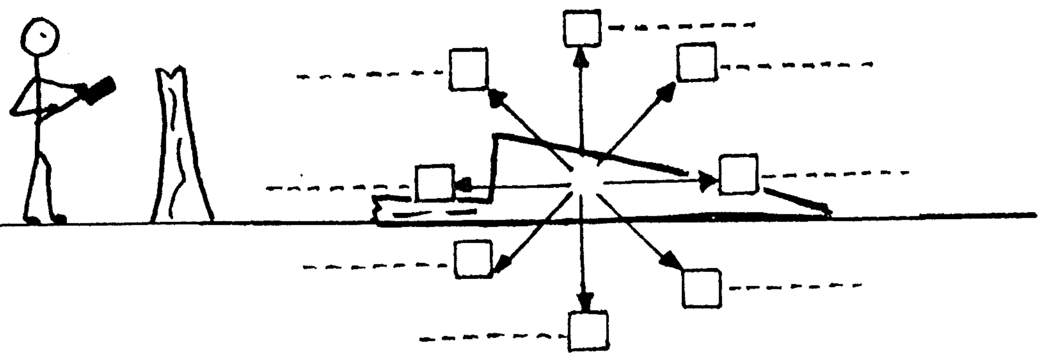
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

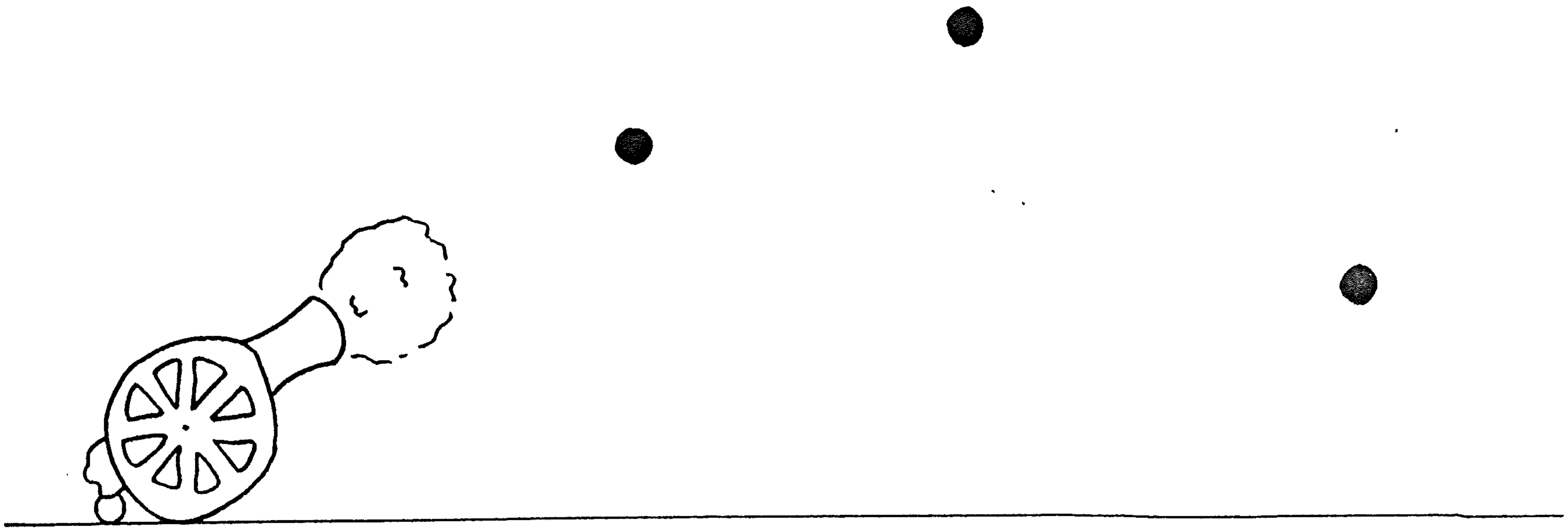
  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UMA BOLA APÓS TER SIDO DISPARADA POR UM CANHÃO



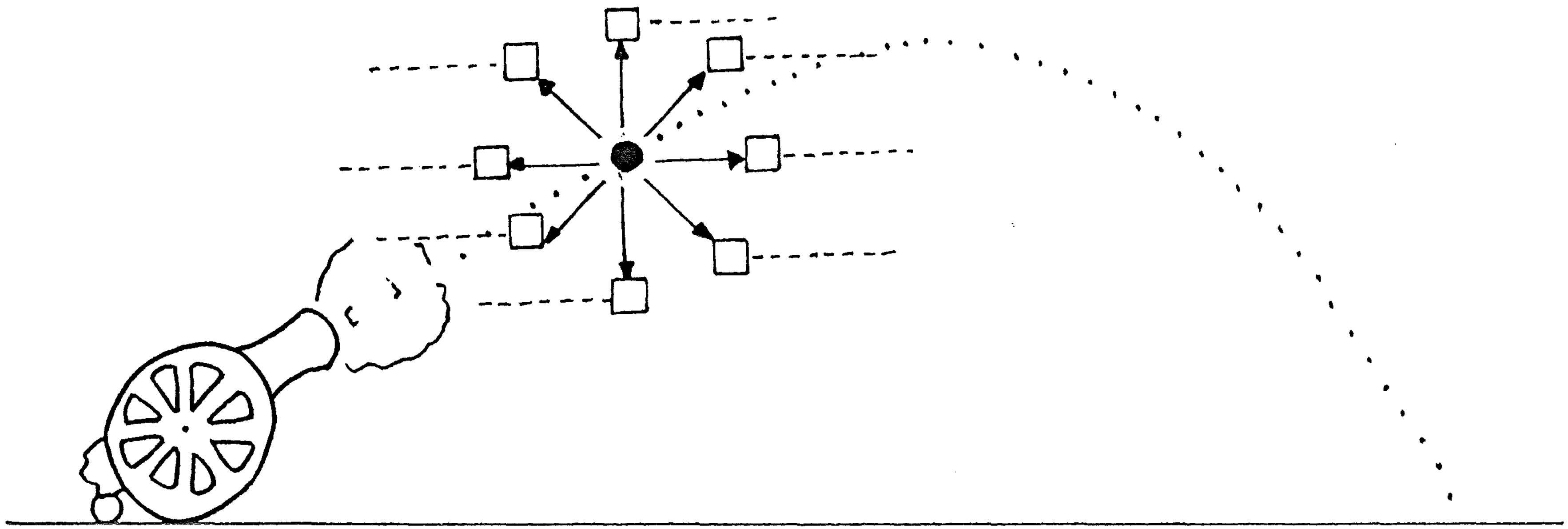
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



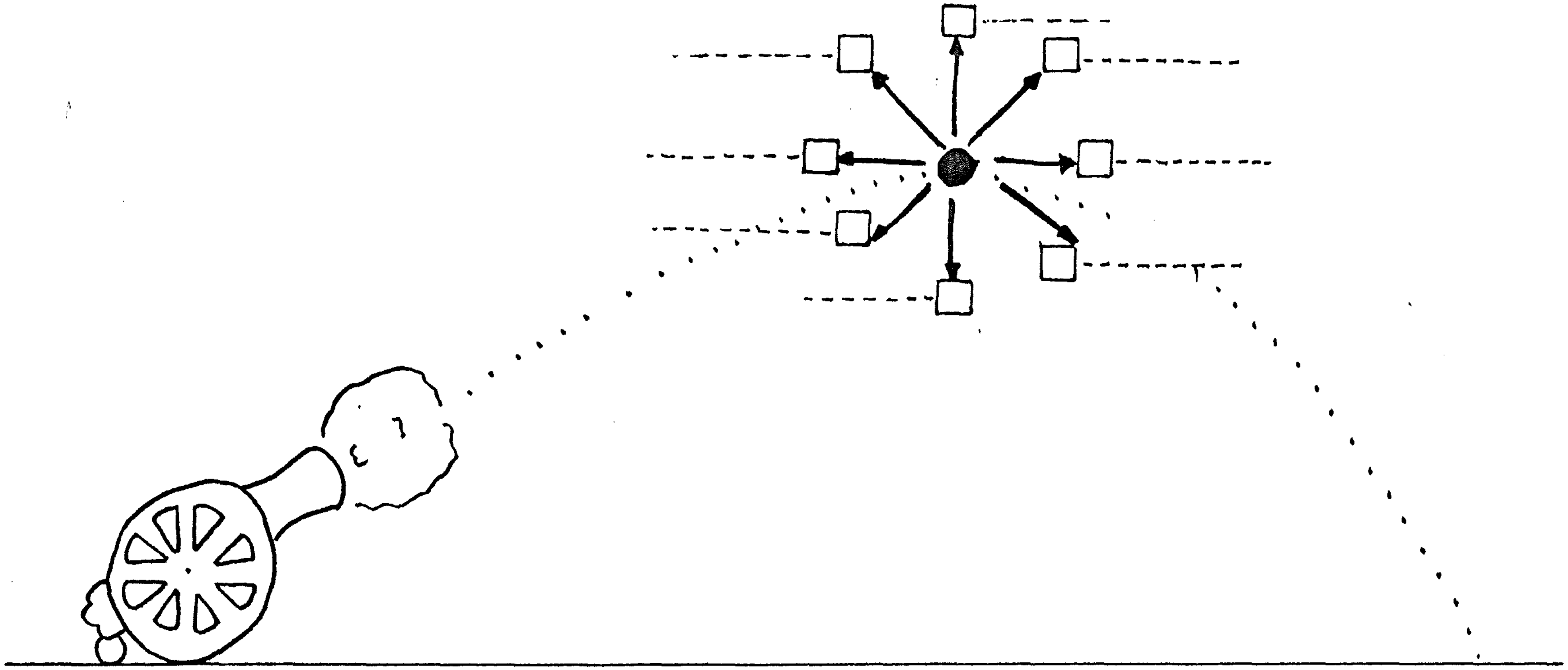
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



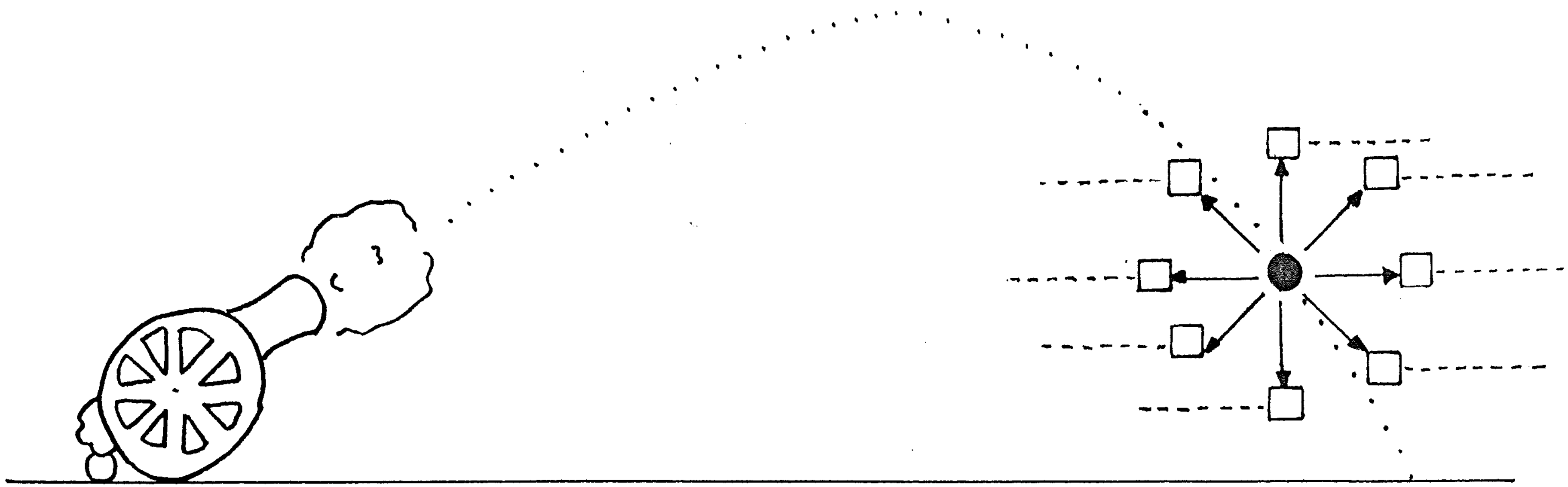
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

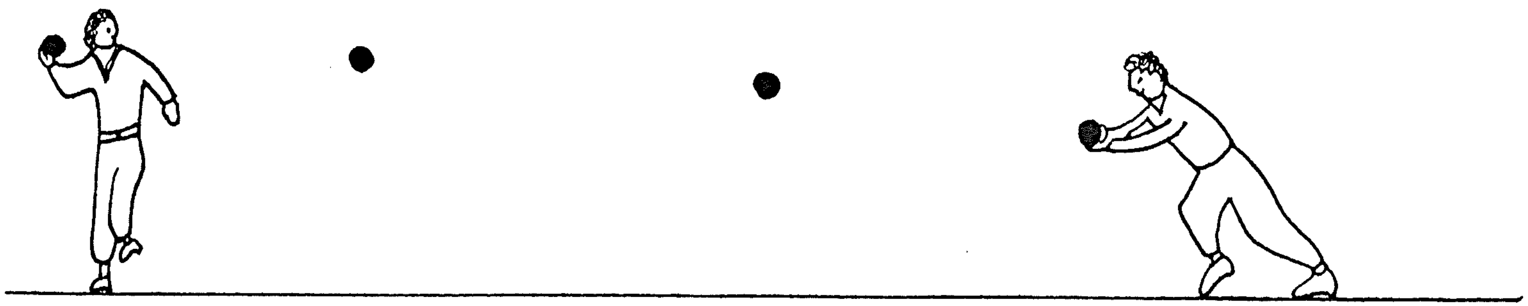
  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UM HOMEM ATIRA UMA BOLA E OUTRO APANHA-A



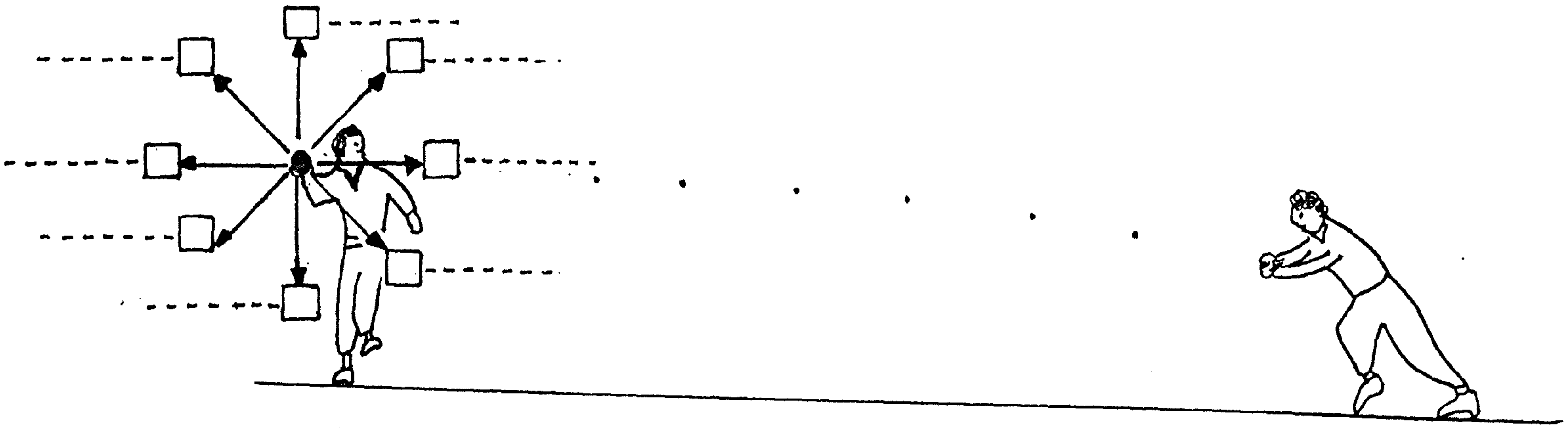
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



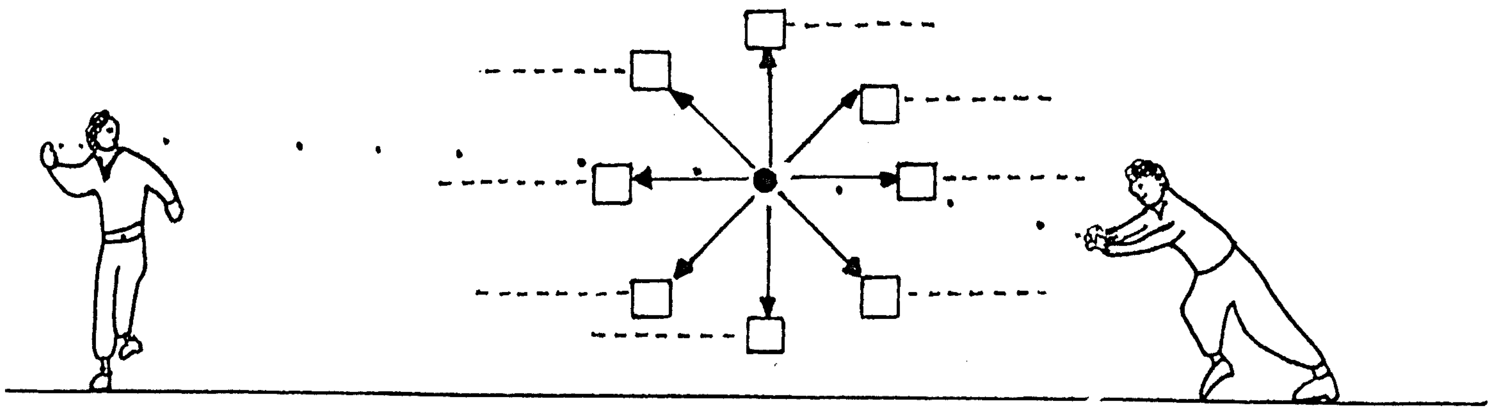
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



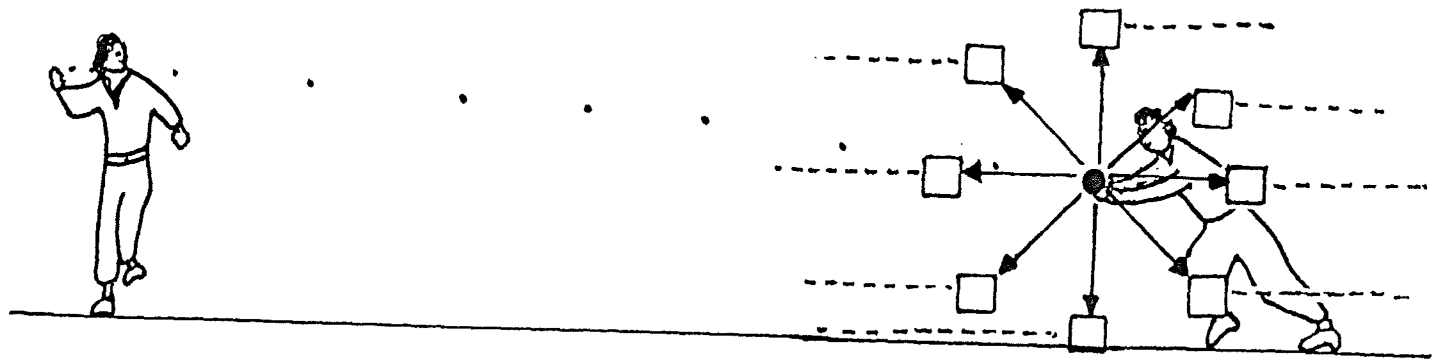
- COLOCA EM CADA QUADRADO:

  ☑ – se existe força

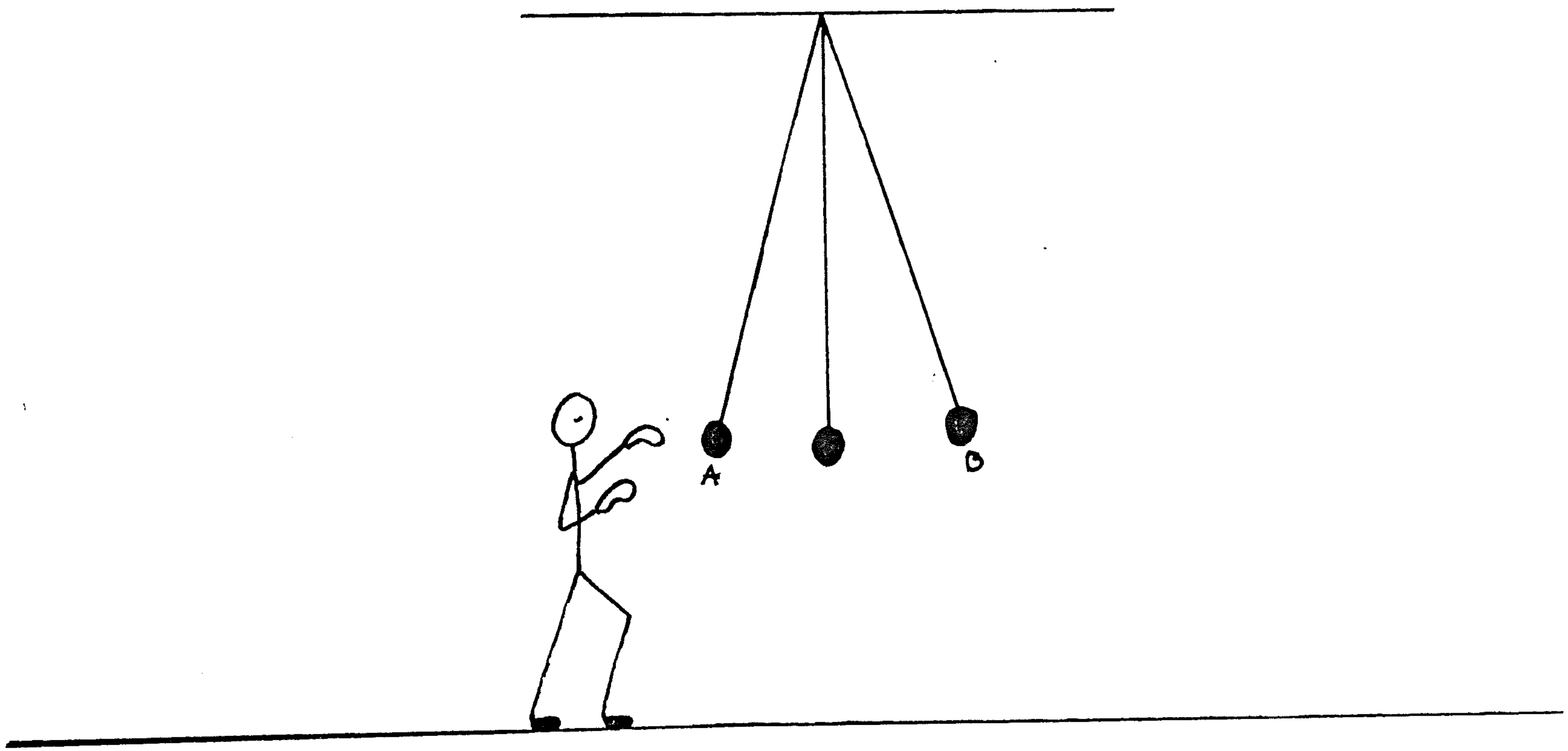
  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



UM JOGADOR EMPURRA UMA BOLA, SUSPENSA POR UM FIO, E ELA OSCILA DE **A** PARA **B**



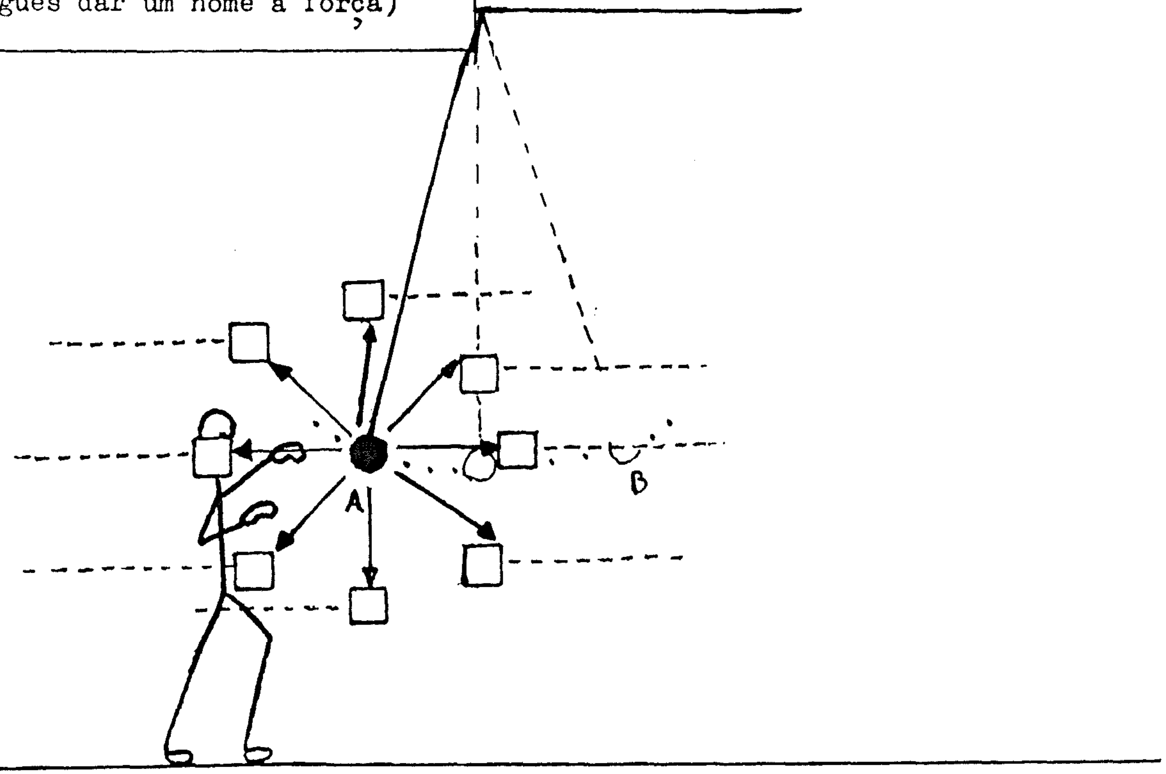
- COLOCA EM CADA QUADRADO:

  [V] – se existe força

  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



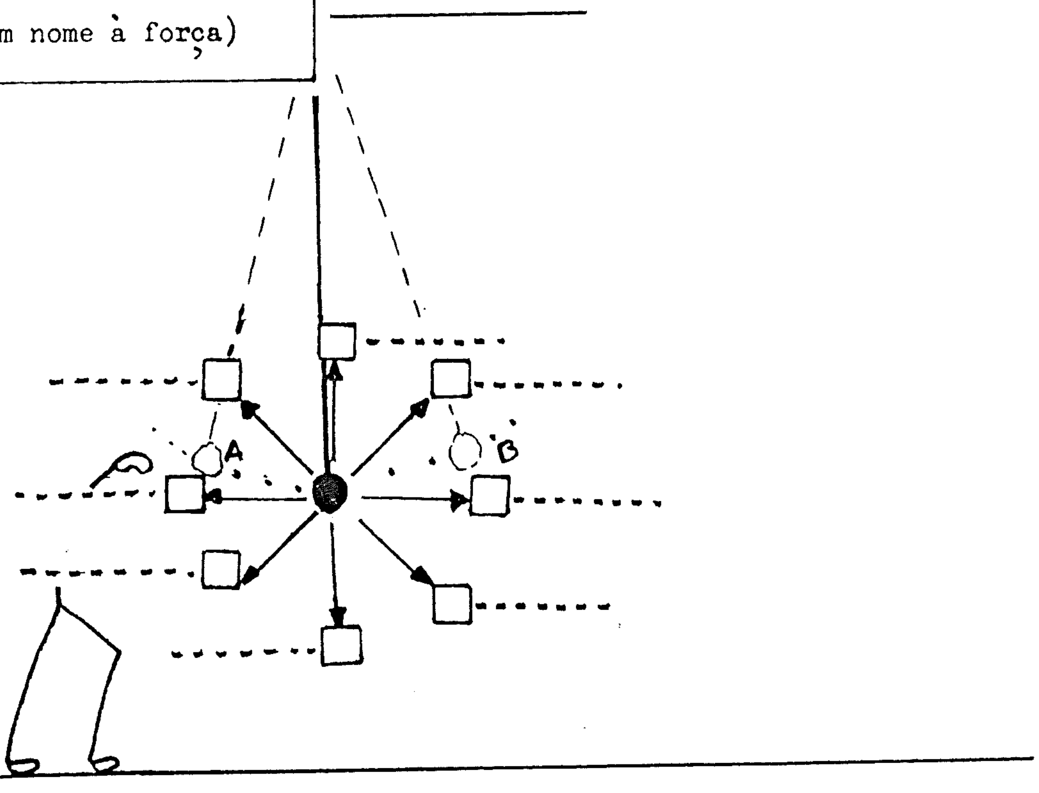
- COLOCA EM CADA QUADRADO:

  [V] – se existe força

  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



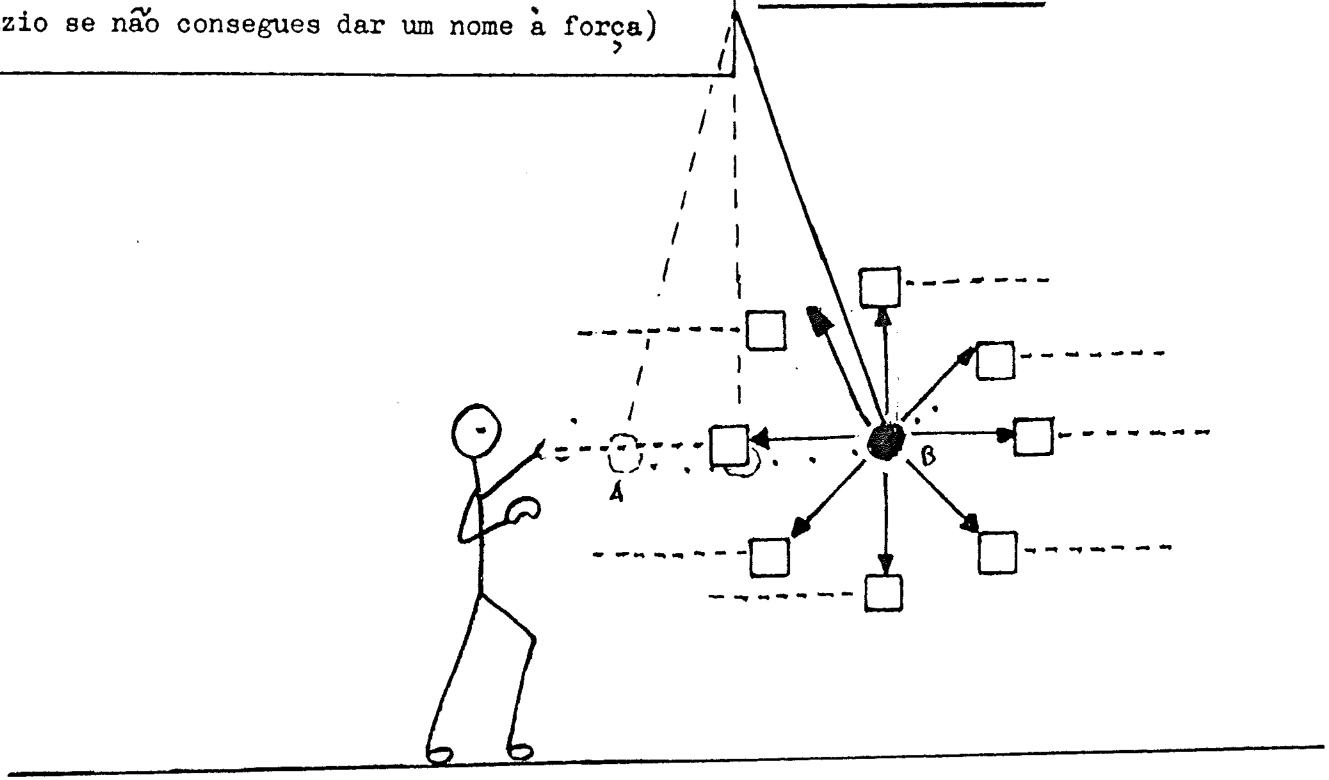
• COLOCA EM CADA QUADRADO:

$\boxed{V}$ – se existe força

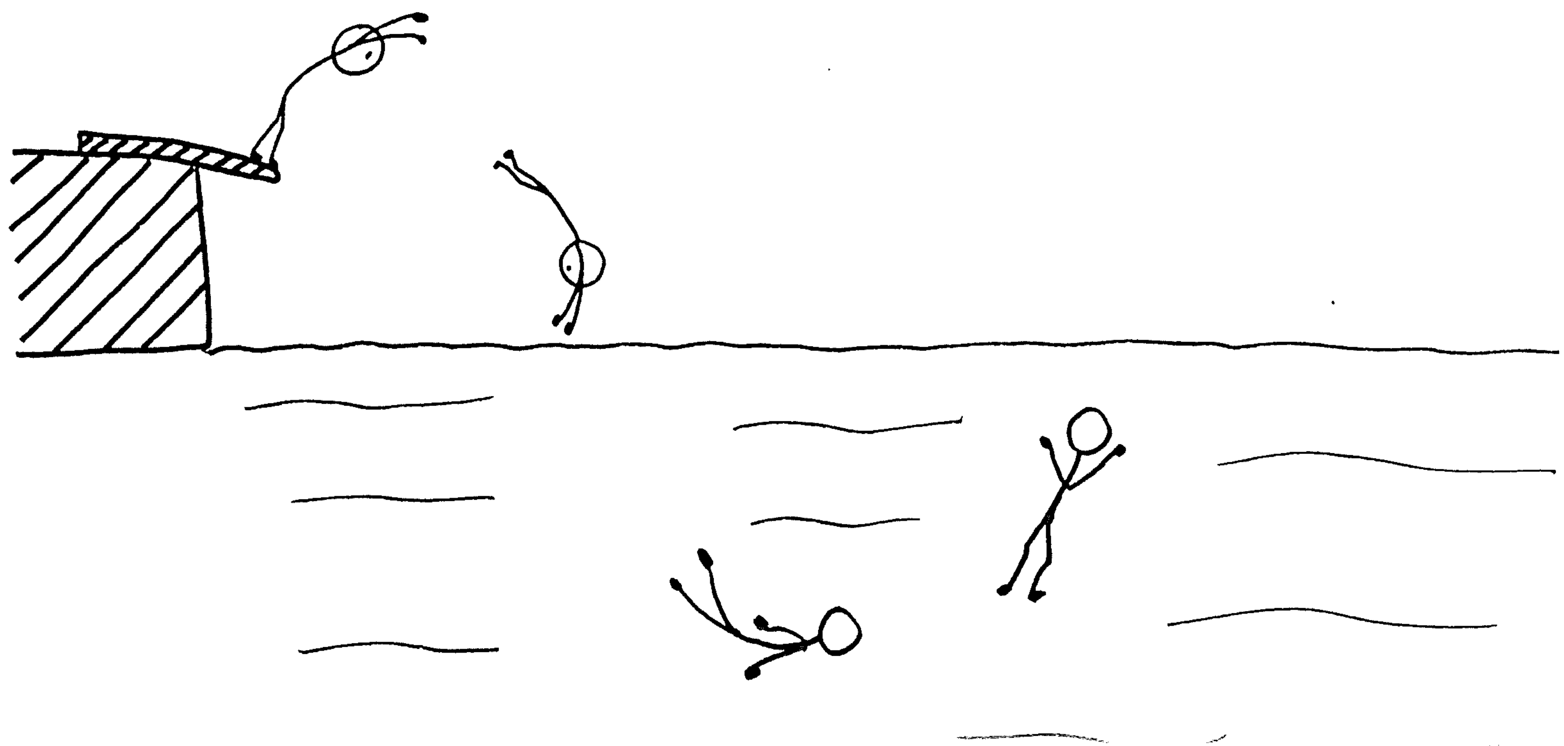
$\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

• ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
(ou deixa o espaço vazio se não consegues dar um nome à força)



UM HOMEM SALTA DE UMA PISCINA, MERGULHA E VOLTA PARA A SUPERFÍCIE



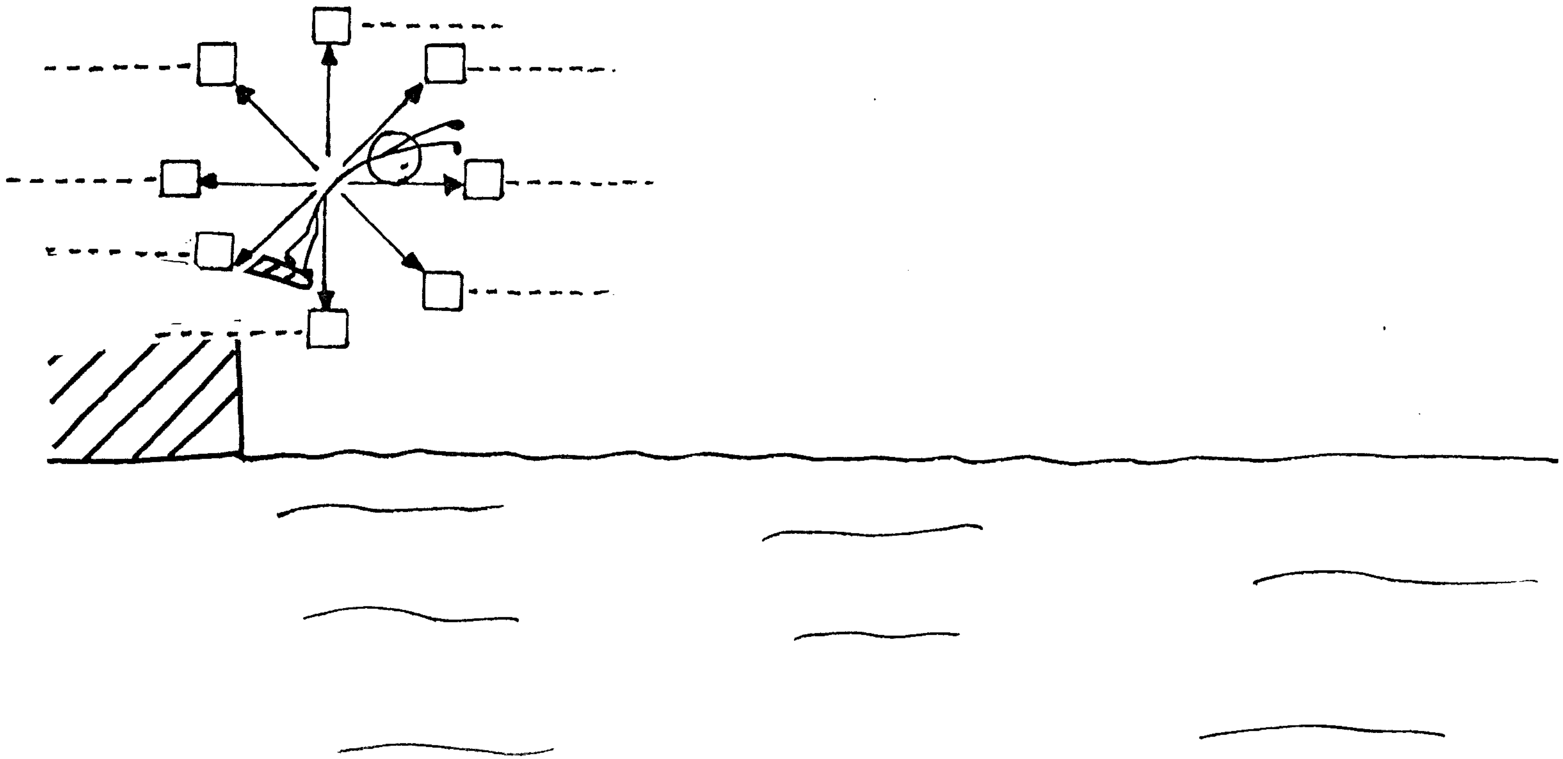
- COLOCA EM CADA QUADRADO:

  [V] – se existe força

  [?] – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



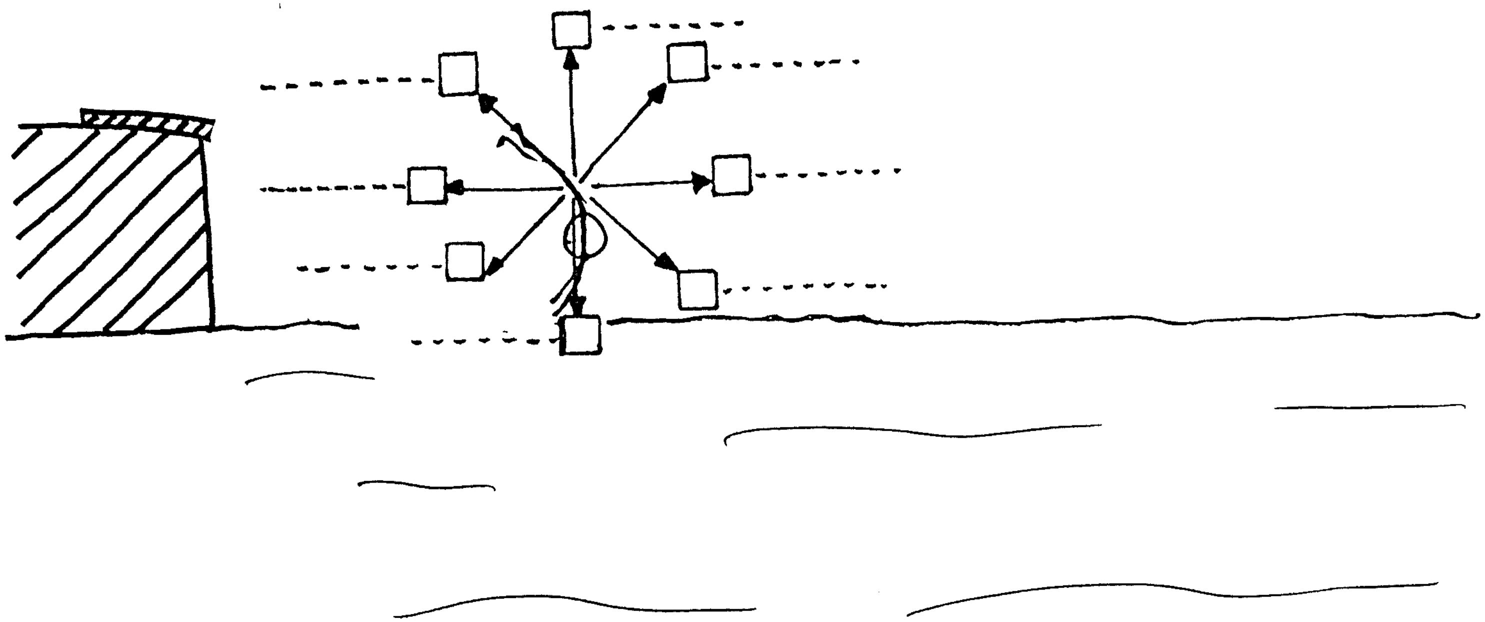
- COLOCA EM CADA QUADRADO:

  $\boxed{\checkmark}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



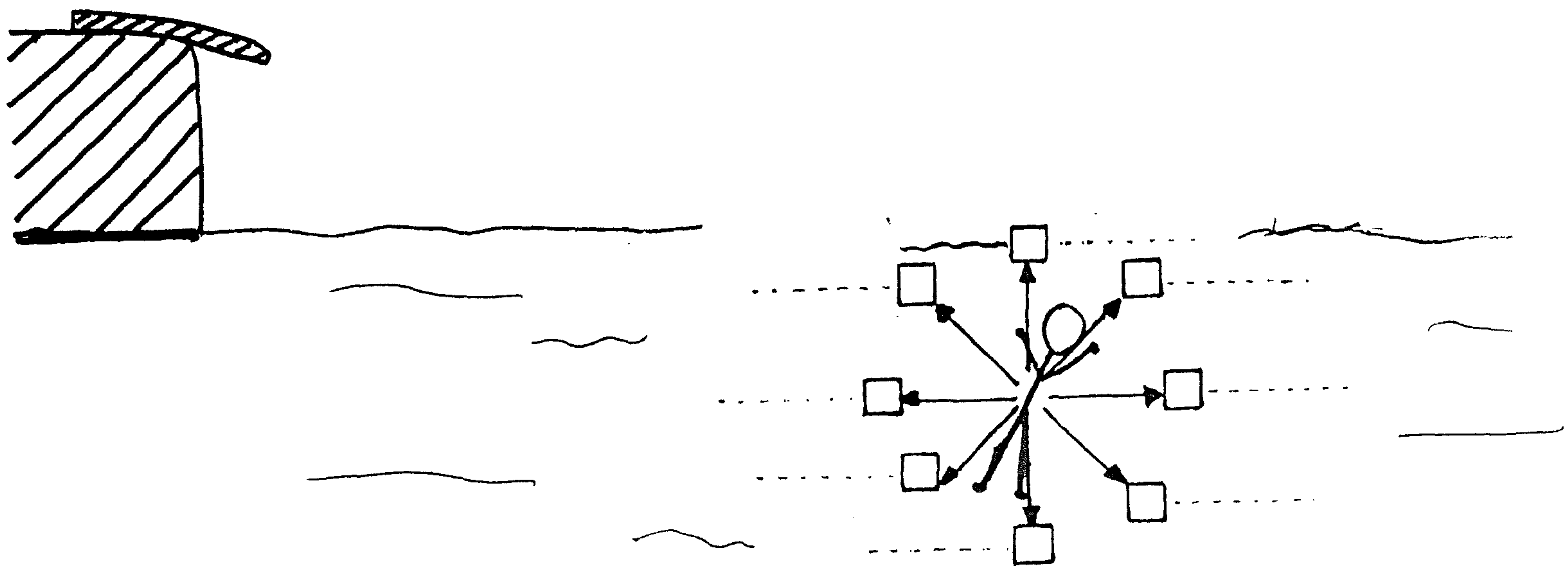
- COLOCA EM CADA QUADRADO:

  $\boxed{V}$ – se existe força

  $\boxed{?}$ – se não tens a certeza se existe força

(ou deixa-o vazio se não existe força)

- ESCREVE, AO LADO DO QUADRADO, UM NOME PARA CADA UMA DAS FORÇAS QUE CONSIDERASTE.
  (ou deixa o espaco vazio se não consegues dar um nome à força)



APPENDIX II

CATEGORIES OF ANSWERS: EXPECTED ANSWERS AND PROBLEMATIC CASES

The following seven tables present the percentage of students' answers according to the different categories of replies defined in Chapter 5, sub-section 5.1.1, namely, **expected answers, undirected forces** (case 1), **component/net forces** (case 2), **others** (case 3 to 6) which include the answers left out of the analysis. Each table corresponde to the results found in all situations for a particular group of students. In the cases where it applies, i.e. groups A, B and C two set of results are given for each situation, corresponding to the two studies done.

GROUP A (STUDY 1 - STUDY 2)

Categories of Answers	Sit. 1						Sit. 2						Sit. 3						Sit. 4					
	1.1		1.2		1.3		2.1		2.2		2.3		3.1		3.2		3.3		4.1		4.2		4.3	
Expected Answers	.6	.75	.5	.8	.5	.85	.65	.8	.6	.75	.6	.7	.6	.75	.4	.7	.6	.75	.6	.8	.5	.7	.6	.8
Case 1 Undirected Forces	.2	.25	.3	.2	.15	.1	.2	.2	.2	.2	.2	.2	.2	.2	.3	.2	.2	.2	.3	.2	.3	.3	.3	.15
Case 2 Comp^{te}/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cases 3 to 6 Answers Left Out	.2	-	.2	-	.35	.05	.15	-	.2	.05	.2	.1	.2	.05	.3	.1	.2	.05	.1	-	.2	-	.1	.05

Categories of Answers	Sit. 5						Sit. 6						Sit. 7						Sit. 8					
	5.1		5.2		5.3		6.1		6.2		6.3		7.1		7.2		7.3		8.1		8.2		8.3	
Expected Answers	.65	.8	.6	.8	.5	.7	.5	.9	.6	.75	.5	.7	.65	.7	.6	.75	.6	.8	.6	.7	.7	.75	.7	.65
Case 1 Undirected Forces	.2	.2	.2	.2	.2	.2	.35	.1	.2	.2	.2	.2	.2	.25	.2	.2	.2	.1	.2	.25	.1	.2	.1	.3
Case 2 Comp^{te}/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cases 3 to 6 Answers Left Out	.15	-	.2	-	.3	.1	.15	-	.2	.05	.3	.1	.15	.05	.2	.05	.2	.1	.2	.05	.2	.05	.2	.05

Study 1 | Study 2

TABLE AII - 1: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP B (STUDY 1 - STUDY 2)

Categories of Answers	Sit. 1						Sit. 2						Sit. 3						Sit. 4					
	1.1		1.2		1.3		2.1		2.2		2.3		3.1		3.2		3.3		4.1		4.2		4.3	
Expected Answers	.9	.8	.9	.85	.9	.7	.85	.65	.9	.8	.9	.7	.85	.8	.9	.7	.9	.75	.85	.7	.9	.6	.7	.75
Case 1 Undirected Forces	.1	.2	.1	.1	.1	.2	.15	.25	.1	.15	.1	.2	.15	.15	.1	.25	.1	.25	.1	.25	.1	.9	.2	.2
Case 2 Comp^{te}/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cases 3 to 6 Answers Left Out	-	-	-	.05	-	.1	-	.1	-	.05	-	.1	-	.05	-	.05	-	-	.05	.05	-	-	.1	.05

Categories of Answers	Sit. 5						Sit. 6						Sit. 7						Sit. 8					
	5.1		5.2		5.3		6.1		6.2		6.3		7.1		7.2		7.3		8.1		8.2		8.3	
Expected Answers	.9	7	.9	.7	.9	.8	.9	.8	.9	.75	.9	.7	.85	.8	.85	.75	.85	.75	.1	.6	.9	.75	.8	.7
Case 1 Undirected Forces	.1	.25	.1	.25	.1	.2	.1	.15	.1	.25	.1	.2	.15	.2	.1	.2	.15	.25	-	.4	.1	.25	.2	.3
Case 2 Comp^{te}/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cases 3 to 6 Answers Left Out	-	.05	-	.05	-	-	-	.05	-	-	-	.1	-	-	.05	.05	-	-	-	-	-	-	-	-

Study 1 | Study 2

TABLE AII - 2: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP C (STUDY 1 - STUDY 2)

Categories of Answers	Sit. 1						Sit. 2						Sit. 3						Sit. 4					
	1.1		1.2		1.3		2.1		2.2		2.3		3.1		3.2		3.3		4.1		4.2		4.3	
Expected Answers	.6	.85	.8	.8	.85	.95	.7	.75	.85	.9	.8	.8	.9	.9	.8	.8	.8	.9	.9	.9	.7	.8	.85	.9
Case 1 Undirected Forces	.15	.1	.15	.1	-	-	.2	.2	.1	.1	.15	.15	-	.05	.15	.1	.15	.05	-	.1	.2	.15	.1	.1
Case 2 Comp^{te}/Net Forces	-	.05	-	.05	-	.05	-	-	-	-	-	.05	-	.05	-	.1	-	.05	-	-	-	.05	-	-
Cases 3 to 6 Answers Left Out	.25	-	.05	.05	.15	-	.1	.05	.05	-	.05	-	.1	-	.05	-	.05	-	.1	-	.1	-	.05	-

Categories of Answers	Sit. 5						Sit. 6						Sit. 7						Sit. 8					
	5.1		5.2		5.3		6.1		6.2		6.3		7.1		7.2		7.3		8.1		8.2		8.3	
Expected Answers	.8	.9	.8	.85	.85	.9	.8	.1	.9	.9	.85	.95	.7	.9	.8	.9	.8	.95	.85	.85	.1	.9	.8	.7
Case 1 Undirected Forces	.15	.05	.15	.1	.05	.05	.1	-	-	.05	.1	.05	.2	.1	.1	.1	.1	.05	.15	.1	.0	.05	.2	.3
Case 2 Comp^{te}/Net Forces	-	.05	.05	.05	-	.05	-	-	-	.05	-	-	-	-	-	-	-	-	-	.05	-	.05	-	-
Cases 3 to 6 Answers Left Out	.05	-	-	-	.1	.0	.1	-	.1	-	.05	-	.1	-	.1	-	.1	-	-	-	-	-	-	-

Study 1 | Study 2

TABLE AII - 3: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP D (STUDY 1 ONLY)

Categories of Answers	Sit. 1			Sit. 2			Sit. 3			Sit.4			Sit. 5			Sit.6			Sit. 7			Sit. 8		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3	8.1	8.2	8.3
Expected Answers	.85	.9	.95	.7	.9	.7	.9	.9	.8	.95	.75	.95	.8	.8	.8	.85	.9	.85	.75	.85	.75	.8	.9	.9
Case 1 Undirected Forces	-	.05	.05	.05	-	.05	-	-	.05	.05	.1	.05	.1	.05	.05	.05	.05	.05	.05	.05	.05	.05	.1	.1
Case 2 Comp^{te}/Net Forces	.05	.05	-	.2	.1	.2	.1	.1	.15	-	.15	-	.1	.15	.15	.05	.05	.05	.2	.1	.2	.1	-	-
Cases 3 to 6 Answers Left Out	.1	-	-	.05	-	.05	-	-	-	-	-	-	-	-	-	.05	-	0.5	-	-	-	0.5	-	-

TABLE AII - 4: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP E (STUDY 2 ONLY)

Categories of Answers	Sit. 1			Sit. 2			Sit. 3			Sit. 4			Sit. 5			Sit. 6			Sit. 7			Sit. 8		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3	8.1	8.2	8.3
Expected Answers	.7	.8	.85	.8	.8	.7	.7	.7	.7	.8	.5	.7	.8	.85	.8	.85	.85	.8	.8	.85	.85	.8	.85	.7
Case 1 Undirected Forces	.3	.2	.1	.2	.2	.3	.3	.3	.3	.2	.5	.3	.2	.15	.2	.15	.15	.2	.2	.15	.15	.2	.15	.3
Case 2 Comp^{te}/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cases 3 to 6 Answers Left Out	-	-	.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE AII - 5: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP F (STUDY 1 ONLY)

Categories of Answers	Sit. 1			Sit. 2			Sit. 3			Sit.4			Sit. 5			Sit.6			Sit. 7			Sit. 8		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3	8.1	8.2	8.3
Expected Answers	.9	.8	.9	.55	.85	.8	.85	.85	.85	.95	.7	.95	.8	.9	.75	.8	.9	.9	.65	.8	.7	.9	.95	.95
Case 1 Undirected Forces	.1	.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.05	-	-	-
Case 2 Comp^{te}/Net Forces	-	.15	.05	.45	.15	.2	.15	.15	.15	-	.25	-	.15	.05	.2	.15	.05	.05	.3	.15	.2	.05	-	-
Cases 3 to 6 Answers Left Out	-	-	.05	.05	-	-	-	-	-	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05

TABLE AII - 6: Percentage of students' answers in the four categories of replies defined in Chapter 5

GROUP G (STUDY 1 ONLY)

Categories of Answers	Sit. 1			Sit. 2			Sit. 3			Sit.4			Sit. 5			Sit.6			Sit. 7			Sit. 8		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3	8.1	8.2	8.3
Expected Answers	.6	.6	.85	.6	.7	.6	.6	.7	.65	.7	.6	.75	.6	.6	.65	.65	.6	.55	NO ANSWERS					
Case 1 Undirected Forces	.2	.35	.1	.35	.25	.35	.3	.25	.3	.25	.35	.2	.3	.35	.3	.25	.35	.35						
Case 2 Compte/Net Forces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
Cases 3 to 6 Answers Left Out	.2	.05	.05	.05	.05	.05	.1	.05	.05	.05	.05	.05	.1	.05	.05	.1	.05	.1						

TABLE AII - 7: Percentage of students' answers in the four categories of replies defined in Chapter 5

APPENDIX III

SUMMARY TABLES OF THE RESULTS OF NAMES GIVEN TO FORCES AND ANALYSIS OF THE PROBLEMATIC RESULTS

The following pages present the results obtained concerning the names given to the forces chosen, by displaying the number of answers found for each category and sub-category of the network described in Chapter 7, sub-section 7.2.3. Next, a discussion is given concerning the analysis of the problematic results, namely those included in the **Unclassified** cases and the **Answers Left Out** of the analysis.

SUMMARY TABLES OF THE RESULTS OF NAMES GIVEN TO FORCES

GROUP: A

SITUATION: 1

Kind of Answers							
Non-named Force/Cause	Nil		N		29	28	9
			Name says nothing		2	6	1
	Replication of the event				3	4	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			0	23	0
		Function of state	Motion/Speed ...		1	2	1
			Energy		4	3	0
		Property of the object			1	4	0
	External to object	Interaction forces	In agreement with the physicist		34	11	11
			Not in agreement with the physicist		22	6	7
		Other causes	Pressure		4	3	7
			Others		4	0	0
Unclassified					2	1	1
Answers left out	Force acting on other object				2	0	0
	Force/Cause finished				0	0	5

GROUP: A

SITUATION: 2

Kind of Answers							
Non-named Force/Cause	Nil		N		33	32	38
			Name says nothing		7	5	5
	Replication of the event				5	5	4
Named Force/cause	Internal to objects	Force/Cause referred to past condition			8	5	3
		Function of state	Motion/Speed ...		7	8	10
			Energy		2	2	0
		Property of the object			5	14	11
	External to object	Interaction forces	In agreement with the physicist		9	9	8
			Not in agreement with the physicist		10	9	12
		Other causes	Pressure		6	4	3
			Others		5	0	0
Unclassified					1	0	0
Answers left out	Force acting on other object				0	0	1
	Force/Cause finished				0	0	1

GROUP: A

SITUATION: 3

Kind of Answers							
Non-named Force/Cause	Nil		N		33	31	30
			Name says nothing		5	5	3
	Replication of the event				6	5	4
Named Force/cause	Internal to objects	Force/Cause referred to past condition			17	5	4
		Function of state	Motion/Speed ...		8	10	11
			Energy		2	2	3
		Property of the object			1	7	2
	External to object	Interaction forces	In agreement with the physicist		8	7	10
			Not in agreement with the physicist		6	13	15
		Other causes	Pressure		4	4	3
			Others		2	1	1
Unclassified					1	1	2
Answers left out	Force acting on other object				2	0	0
	Force/Cause finished				2	1	0

GROUP: A

SITUATION: 4

Kind of Answers							
Non-named Force/Cause	Nil		N		19	29	18
			Name says nothing		2	1	1
	Replication of the event				2	7	2
Named Force/cause	Internal to objects	Force/Cause referred to past condition			11	4	2
		Function of state	Motion/Speed ...		0	7	0
			Energy		2	2	0
		Property of the object			4	3	1
	External to object	Interaction forces	In agreement with the physicist		7	9	12
			Not in agreement with the physicist		7	15	9
		Other causes	Pressure		3	4	4
			Others		0	1	0
Unclassified					4	1	1
Answers left out	Force acting on other object				1	0	1
	Force/Cause finished				0	0	0

GROUP: A

SITUATION: 5

Kind of Answers			
Non-named Force/Cause – Nil – N	27	29	30
Non-named Force/Cause – Nil – Name says nothing	5	3	2
Non-named Force/Cause – Replication of the event	5	3	6
Named Force/cause – Internal to objects – Force/Cause referred to past condition	22	14	6
Named Force/cause – Internal to objects – Function of state – Motion/Speed ...	6	4	4
Named Force/cause – Internal to objects – Function of state – Energy	4	1	2
Named Force/cause – Internal to objects – Property of the object	2	4	2
Named Force/cause – External to object – Interaction forces – In agreement with the physicist	9	6	10
Named Force/cause – External to object – Interaction forces – Not in agreement with the physicist	6	15	15
Named Force/cause – External to object – Other causes – Pressure	3	3	5
Named Force/cause – External to object – Other causes – Others	0	0	0
Unclassified	2	1	0
Answers left out – Force acting on other object	0	0	0
Answers left out – Force/Cause finished	0	1	3

GROUP: A

SITUATION: 7

Kind of Answers			
Non-named Force/Cause – Nil – N	30	35	29
Non-named Force/Cause – Nil – Name says nothing	0	3	1
Non-named Force/Cause – Replication of the event	1	0	0
Named Force/cause – Internal to objects – Force/Cause referred to past condition	26	12	9
Named Force/cause – Internal to objects – Function of state – Motion/Speed ...	3	4	5
Named Force/cause – Internal to objects – Function of state – Energy	4	1	1
Named Force/cause – Internal to objects – Property of the object	0	3	2
Named Force/cause – External to object – Interaction forces – In agreement with the physicist	7	11	10
Named Force/cause – External to object – Interaction forces – Not in agreement with the physicist	8	5	4
Named Force/cause – External to object – Other causes – Pressure	2	2	4
Named Force/cause – External to object – Other causes – Others	0	0	0
Unclassified	1	3	5
Answers left out – Force acting on other object	0	0	0
Answers left out – Force/Cause finished	0	0	0

GROUP: A

SITUATION: 6

Kind of Answers			
Non-named Force/Cause – Nil – N	19	31	21
Non-named Force/Cause – Nil – Name says nothing	2	2	0
Non-named Force/Cause – Replication of the event	0	1	1
Named Force/cause – Internal to objects – Force/Cause referred to past condition	0	15	1
Named Force/cause – Internal to objects – Function of state – Motion/Speed ...	0	8	4
Named Force/cause – Internal to objects – Function of state – Energy	4	3	2
Named Force/cause – Internal to objects – Property of the object	1	5	2
Named Force/cause – External to object – Interaction forces – In agreement with the physicist	29	8	13
Named Force/cause – External to object – Interaction forces – Not in agreement with the physicist	14	8	11
Named Force/cause – External to object – Other causes – Pressure	4	4	4
Named Force/cause – External to object – Other causes – Others	2	0	0
Unclassified	2	1	8
Answers left out – Force acting on other object	1	0	0
Answers left out – Force/Cause finished	0	1	4

GROUP: A

SITUATION: 8

Kind of Answers			
Non-named Force/Cause – Nil – N	29	31	31
Non-named Force/Cause – Nil – Name says nothing	3	0	2
Non-named Force/Cause – Replication of the event	5	7	8
Named Force/cause – Internal to objects – Force/Cause referred to past condition	0	3	0
Named Force/cause – Internal to objects – Function of state – Motion/Speed ...	3	4	7
Named Force/cause – Internal to objects – Function of state – Energy	3	2	4
Named Force/cause – Internal to objects – Property of the object	7	3	6
Named Force/cause – External to object – Interaction forces – In agreement with the physicist	10	16	7
Named Force/cause – External to object – Interaction forces – Not in agreement with the physicist	23	8	11
Named Force/cause – External to object – Other causes – Pressure	3	4	5
Named Force/cause – External to object – Other causes – Others	2	0	0
Unclassified	3	2	1
Answers left out – Force acting on other object	2	0	1
Answers left out – Force/Cause finished	0	0	0

GROUP: B

SITUATION: 1

Kind of Answers						
Non-named Force/Cause	Nil	N		42	41	31
		Name says nothing		8	4	0
	Replication of the event			0	1	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	10	2
		Function of state	Motion/Speed ...	0	9	0
			Energy	0	1	0
		Property of the object		1	0	0
	External to object	Interaction forces	In agreement with the physicist	65	56	38
			Not in agreement with the physicist	26	19	34
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				4	0	5
Answers left out	Force acting on other object			2	3	4
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 3

Kind of Answers						
Non-named Force/Cause	Nil	N		38	37	37
		Name says nothing		4	2	2
	Replication of the event			0	1	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		3	2	1
		Function of state	Motion/Speed ...	11	11	12
			Energy	1	0	1
		Property of the object		3	2	0
	External to object	Interaction forces	In agreement with the physicist	57	54	34
			Not in agreement with the physicist	22	29	39
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				0	2	0
Answers left out	Force acting on other object			2	1	0
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 2

Kind of Answers						
Non-named Force/Cause	Nil	N		36	40	51
		Name says nothing		7	4	3
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		1	0	0
		Function of state	Motion/Speed ...	10	7	6
			Energy	0	0	0
		Property of the object		2	3	4
	External to object	Interaction forces	In agreement with the physicist	43	50	46
			Not in agreement with the physicist	33	32	37
		Other causes	Pressure	0	0	0
			Others	1	0	0
Unclassified				1	1	2
Answers left out	Force acting on other object			6	3	3
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 4

Kind of Answers						
Non-named Force/Cause	Nil	N		31	31	33
		Name says nothing		2	1	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		1	1	0
		Function of state	Motion/Speed ...	0	9	0
			Energy	0	0	1
		Property of the object		1	1	1
	External to object	Interaction forces	In agreement with the physicist	30	29	32
			Not in agreement with the physicist	21	43	29
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				3	1	3
Answers left out	Force acting on other object			2	0	2
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 5

Kind of Answers						
Non-named Force/Cause	Nil	N		42	37	36
		Name says nothing		6	4	2
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		4	2	1
		Function of state	Motion/Speed ...	10	10	9
			Energy	0	0	0
		Property of the object		4	2	3
	External to object	Interaction forces	In agreement with the physicist	41	41	40
			Not in agreement with the physicist	19	29	26
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				3	2	2
Answers left out	Force acting on other object			2	1	0
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 7

Kind of Answers						
Non-named Force/Cause	Nil	N		58	60	61
		Name says nothing		2	1	2
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		6	5	3
		Function of state	Motion/Speed ...	5	5	5
			Energy	0	0	0
		Property of the object		1	2	0
	External to object	Interaction forces	In agreement with the physicist	40	40	40
			Not in agreement with the physicist	17	18	15
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				1	1	1
Answers left out	Force acting on other object			0	1	0
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 6

Kind of Answers						
Non-named Force/Cause	Nil	N		51	45	49
		Name says nothing		6	2	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	9	1
		Function of state	Motion/Speed ...	0	11	3
			Energy	1	0	0
		Property of the object		0	2	1
	External to object	Interaction forces	In agreement with the physicist	45	47	42
			Not in agreement with the physicist	29	20	24
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				3	0	3
Answers left out	Force acting on other object			0	1	3
	Force/Cause finished			0	0	0

GROUP: B

SITUATION: 8

Kind of Answers						
Non-named Force/Cause	Nil	N		45	40	52
		Name says nothing		7	0	2
	Replication of the event			0	0	1
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
		Function of state	Motion/Speed ...	0	7	3
			Energy	0	0	0
		Property of the object		4	2	2
	External to object	Interaction forces	In agreement with the physicist	31	40	26
			Not in agreement with the physicist	33	19	19
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				3	0	1
Answers left out	Force acting on other object			1	0	0
	Force/Cause finished			0	0	0

GROUP: C

SITUATION: 1

Kind of Answers							
Non-named Force/Cause	Nil	N			32	39	25
		Name says nothing			2	9	0
	Replication of the event				2	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			0	15	0
		Function of state	Motion/Speed ...		0	7	0
			Energy		1	1	2
		Property of the object			0	0	0
	External to object	Interaction forces	In agreement with the physicist		83	72	54
			Not in agreement with the physicist		17	13	7
		Other causes	Pressure		1	1	1
			Others		0	0	0
Unclassified					9	4	0
Answers left out	Force acting on other object				4	1	2
	Force/Cause finished				0	1	0

GROUP: C

SITUATION: 3

Kind of Answers							
Non-named Force/Cause	Nil	N			45	58	40
		Name says nothing			5	7	4
	Replication of the event				0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			10	8	7
		Function of state	Motion/Speed ...		6	7	5
			Energy		1	1	0
		Property of the object			2	0	1
	External to object	Interaction forces	In agreement with the physicist		69	57	47
			Not in agreement with the physicist		13	14	12
		Other causes	Pressure		1	1	0
			Others		0	1	1
Unclassified					7	4	5
Answers left out	Force acting on other object				1	1	1
	Force/Cause finished				0	0	0

GROUP: C

SITUATION: 2

Kind of Answers							
Non-named Force/Cause	Nil	N			48	53	59
		Name says nothing			8	6	7
	Replication of the event				0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			7	8	8
		Function of state	Motion/Speed ...		6	7	4
			Energy		1	0	0
		Property of the object			1	1	1
	External to object	Interaction forces	In agreement with the physicist		56	72	57
			Not in agreement with the physicist		24	8	24
		Other causes	Pressure		1	1	1
			Others		0	0	0
Unclassified					8	5	8
Answers left out	Force acting on other object				1	1	1
	Force/Cause finished				0	0	0

GROUP: C

SITUATION: 4

Kind of Answers							
Non-named Force/Cause	Nil	N			31	47	28
		Name says nothing			5	6	2
	Replication of the event				0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			3	6	0
		Function of state	Motion/Speed ...		0	3	0
			Energy		0	0	0
		Property of the object			0	0	0
	External to object	Interaction forces	In agreement with the physicist		43	41	51
			Not in agreement with the physicist		5	15	5
		Other causes	Pressure		1	1	1
			Others		0	0	0
Unclassified					1	3	2
Answers left out	Force acting on other object				1	1	1
	Force/Cause finished				0	0	0

GROUP: C

SITUATION: 5

Kind of Answers			
Non-named Force/Cause — Nil — N	46	47	38
Non-named Force/Cause — Nil — Name says nothing	7	6	4
Non-named Force/Cause — Replication of the event	0	1	1
Named Force/cause — Internal to objects — Force/Cause referred to past condition	14	8	6
Named Force/cause — Internal to objects — Function of state — Motion/Speed ...	8	9	8
Named Force/cause — Internal to objects — Function of state — Energy	0	0	0
Named Force/cause — Internal to objects — Property of the object	0	0	0
Named Force/cause — External to object — Interaction forces — In agreement with the physicist	52	42	52
Named Force/cause — External to object — Interaction forces — Not in agreement with the physicist	5	18	7
Named Force/cause — External to object — Other causes — Pressure	1	1	1
Named Force/cause — External to object — Other causes — Others	0	0	0
Unclassified	4	3	3
Answers left out — Force acting on other object	1	1	1
Answers left out — Force/Cause finished	0	0	0

GROUP: C

SITUATION: 7

Kind of Answers			
Non-named Force/Cause — Nil — N	67	67	70
Non-named Force/Cause — Nil — Name says nothing	6	2	3
Non-named Force/Cause — Replication of the event	0	0	0
Named Force/cause — Internal to objects — Force/Cause referred to past condition	9	8	8
Named Force/cause — Internal to objects — Function of state — Motion/Speed ...	6	5	4
Named Force/cause — Internal to objects — Function of state — Energy	0	0	0
Named Force/cause — Internal to objects — Property of the object	0	1	1
Named Force/cause — External to object — Interaction forces — In agreement with the physicist	44	48	44
Named Force/cause — External to object — Interaction forces — Not in agreement with the physicist	10	6	3
Named Force/cause — External to object — Other causes — Pressure	1	1	1
Named Force/cause — External to object — Other causes — Others	0	0	0
Unclassified	5	3	3
Answers left out — Force acting on other object	1	1	1
Answers left out — Force/Cause finished	0	0	0

GROUP: C

SITUATION: 6

Kind of Answers			
Non-named Force/Cause — Nil — N	48	54	62
Non-named Force/Cause — Nil — Name says nothing	3	4	0
Non-named Force/Cause — Replication of the event	0	0	1
Named Force/cause — Internal to objects — Force/Cause referred to past condition	0	13	6
Named Force/cause — Internal to objects — Function of state — Motion/Speed ...	0	6	1
Named Force/cause — Internal to objects — Function of state — Energy	0	0	0
Named Force/cause — Internal to objects — Property of the object	0	1	0
Named Force/cause — External to object — Interaction forces — In agreement with the physicist	58	54	46
Named Force/cause — External to object — Interaction forces — Not in agreement with the physicist	6	4	3
Named Force/cause — External to object — Other causes — Pressure	2	1	1
Named Force/cause — External to object — Other causes — Others	0	0	0
Unclassified	2	2	5
Answers left out — Force acting on other object	2	1	2
Answers left out — Force/Cause finished	0	0	0

GROUP: C

SITUATION: 8

Kind of Answers			
Non-named Force/Cause — Nil — N	54	40	55
Non-named Force/Cause — Nil — Name says nothing	1	0	0
Non-named Force/Cause — Replication of the event	0	0	0
Named Force/cause — Internal to objects — Force/Cause referred to past condition	0	2	0
Named Force/cause — Internal to objects — Function of state — Motion/Speed ...	0	2	4
Named Force/cause — Internal to objects — Function of state — Energy	0	0	0
Named Force/cause — Internal to objects — Property of the object	2	1	3
Named Force/cause — External to object — Interaction forces — In agreement with the physicist	37	41	38
Named Force/cause — External to object — Interaction forces — Not in agreement with the physicist	23	4	7
Named Force/cause — External to object — Other causes — Pressure	1	1	2
Named Force/cause — External to object — Other causes — Others	0	0	0
Unclassified	3	4	1
Answers left out — Force acting on other object	0	0	0
Answers left out — Force/Cause finished	0	0	0

GROUP: D

SITUATION: 1

Kind of Answers						
Non-named Force/Cause	Nil	N		21	14	5
Non-named Force/Cause	Nil	Name says nothing		6	7	1
Non-named Force/Cause	Replication of the event			0	0	1
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	13	2
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	5	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	2	1
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	172	181	118
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	7	5	19
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				2	2	1
Answers left out	Force acting on other object			9	2	2
Answers left out	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 3

Kind of Answers						
Non-named Force/Cause	Nil	N		11	10	10
Non-named Force/Cause	Nil	Name says nothing		12	12	9
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		10	8	4
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	5	3	1
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		1	1	1
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	178	163	96
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	7	7	33
Named Force/cause	External to object	Other causes	Pressure	0	1	1
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				2	0	8
Answers left out	Force acting on other object			1	1	0
Answers left out	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 2

Kind of Answers						
Non-named Force/Cause	Nil	N		19	21	16
Non-named Force/Cause	Nil	Name says nothing		12	8	10
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		1	1	1
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	2	1	3
Named Force/cause	Internal to objects	Function of state	Energy	1	2	1
Named Force/cause	Internal to objects	Property of the object		1	1	2
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	166	167	149
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	25	6	38
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				4	4	7
Answers left out	Force acting on other object			3	1	3
Answers left out	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 4

Kind of Answers						
Non-named Force/Cause	Nil	N		10	21	8
Non-named Force/Cause	Nil	Name says nothing		2	5	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		6	4	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	1	0
Named Force/cause	Internal to objects	Property of the object		0	1	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	105	92	114
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	5	20	1
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				3	21	1
Answers left out	Force acting on other object			1	1	1
Answers left out	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 5

Kind of Answers						
Non-named Force/Cause	Nil	N		17	16	11
		Name says nothing		7	8	8
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		16	5	3
		Function of state	Motion/Speed ...	4	3	2
			Energy	0	0	0
		Property of the object		1	1	1
	External to object	Interaction forces	In agreement with the physicist	107	93	100
			Not in agreement with the physicist	19	23	20
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				8	6	5
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 6

Kind of Answers						
Non-named Force/Cause	Nil	N		15	16	20
		Name says nothing		2	7	1
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	16	3
		Function of state	Motion/Speed ...	2	3	1
			Energy	0	0	0
		Property of the object		0	1	1
	External to object	Interaction forces	In agreement with the physicist	141	112	133
			Not in agreement with the physicist	13	17	10
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				0	7	1
Answers left out	Force acting on other object			8	0	12
	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 7

Kind of Answers						
Non-named Force/Cause	Nil	N		20	17	23
		Name says nothing		8	6	10
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		3	2	2
		Function of state	Motion/Speed ...	1	3	2
			Energy	0	1	0
		Property of the object		1	2	1
	External to object	Interaction forces	In agreement with the physicist	148	140	137
			Not in agreement with the physicist	22	9	26
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				14	1	11
Answers left out	Force acting on other object			1	1	1
	Force/Cause finished			0	0	0

GROUP: D

SITUATION: 8

Kind of Answers						
Non-named Force/Cause	Nil	N		26	16	17
		Name says nothing		6	5	2
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
		Function of state	Motion/Speed ...	0	1	0
			Energy	0	0	0
		Property of the object		8	1	4
	External to object	Interaction forces	In agreement with the physicist	122	72	114
			Not in agreement with the physicist	15	27	11
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				4	8	2
Answers left out	Force acting on other object			7	0	1
	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 1

Kind of Answers				32	37	22
Non-named Force/Cause	Nil	N				
		Name says nothing		1	0	1
	Replication of the event			1	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	5	2
		Function of state	Motion/Speed ...	0	4	0
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	8	7	7
			Not in agreement with the physicist	10	7	6
		Other causes	Pressure	0	0	0
			Others	1	0	0
Unclassified				5	6	5
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	1

GROUP: E

SITUATION: 3

Kind of Answers				36	34	33
Non-named Force/Cause	Nil	N				
		Name says nothing		0	0	0
	Replication of the event			0	0	1
Named Force/cause	Internal to objects	Force/Cause referred to past condition		3	3	2
		Function of state	Motion/Speed ...	3	1	1
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	6	3	5
			Not in agreement with the physicist	5	13	8
		Other causes	Pressure	0	1	2
			Others	1	0	0
Unclassified				3	3	2
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 2

Kind of Answers				36	39	42
Non-named Force/Cause	Nil	N				
		Name says nothing		0	0	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		2	3	3
		Function of state	Motion/Speed ...	4	2	2
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	6	5	5
			Not in agreement with the physicist	5	7	5
		Other causes	Pressure	0	0	0
			Others	2	0	1
Unclassified				4	4	4
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 4

Kind of Answers				27	37	18
Non-named Force/Cause	Nil	N				
		Name says nothing		3	1	1
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	2	1
		Function of state	Motion/Speed ...	0	1	0
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	5	4	5
			Not in agreement with the physicist	2	7	4
		Other causes	Pressure	0	1	0
			Others	0	0	0
Unclassified				2	2	3
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 5

Kind of Answers						
		N		35	35	30
Non-named Force/Cause	Nil	Name says nothing		2	0	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		7	4	2
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	3	1	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	5	4	6
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	4	7	9
Named Force/cause	External to object	Other causes	Pressure	0	0	1
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				3	3	3
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 7

Kind of Answers						
		N		36	40	37
Non-named Force/Cause	Nil	Name says nothing		1	1	1
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		5	3	3
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	3	2	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	4	4	4
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	4	4	4
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				3	4	4
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 6

Kind of Answers						
		N		34	34	35
Non-named Force/Cause	Nil	Name says nothing		1	0	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	3	3
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	3	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	9	5	4
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	5	6	5
Named Force/cause	External to object	Other causes	Pressure	0	1	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				2	5	4
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: E

SITUATION: 8

Kind of Answers						
		N		37	33	36
Non-named Force/Cause	Nil	Name says nothing		2	1	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		4	0	2
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	4	7	5
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	6	3	4
Named Force/cause	External to object	Other causes	Pressure	0	1	1
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				4	2	3
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 1

Kind of Answers						
Non-named Force/Cause	Nil	N		2	0	0
Non-named Force/Cause	Nil	Name says nothing		3	0	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	3	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	61	53	38
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	2	1	2
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				0	0	0
Answers left out	Force acting on other object			8	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 3

Kind of Answers						
Non-named Force/Cause	Nil	N		0	0	0
Non-named Force/Cause	Nil	Name says nothing		2	1	1
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	1	1	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	49	46	18
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	4	2	13
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				0	0	1
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 2

Kind of Answers						
Non-named Force/Cause	Nil	N		1	2	1
Non-named Force/Cause	Nil	Name says nothing		1	2	1
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	3	1	3
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	53	51	54
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	8	3	13
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				0	0	0
Answers left out	Force acting on other object			0	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 4

Kind of Answers						
Non-named Force/Cause	Nil	N		0	0	0
Non-named Force/Cause	Nil	Name says nothing		0	3	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		4	1	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	32	26	32
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	0	3	0
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				0	5	0
Answers left out	Force acting on other object			4	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 5

Kind of Answers						
Non-named Force/Cause	Nil	N		2	0	0
Non-named Force/Cause	Nil	Name says nothing		1	2	2
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		5	1	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	1	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	31	30	29
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	4	2	9
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				3	5	2
Answers left out	Force acting on other object			2	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 7

Kind of Answers						
Non-named Force/Cause	Nil	N		0	0	0
Non-named Force/Cause	Nil	Name says nothing		2	1	2
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	44	43	41
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	3	2	5
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				4	3	4
Answers left out	Force acting on other object			1	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 6

Kind of Answers						
Non-named Force/Cause	Nil	N		4	0	4
Non-named Force/Cause	Nil	Name says nothing		0	0	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	1	2
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	1
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	50	30	34
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	1	5	2
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				1	4	2
Answers left out	Force acting on other object			1	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: F

SITUATION: 8

Kind of Answers						
Non-named Force/Cause	Nil	N		3	0	0
Non-named Force/Cause	Nil	Name says nothing		2	0	0
Non-named Force/Cause	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
Named Force/cause	Internal to objects	Function of state	Motion/Speed ...	0	0	0
Named Force/cause	Internal to objects	Function of state	Energy	0	0	0
Named Force/cause	Internal to objects	Property of the object		0	0	0
Named Force/cause	External to object	Interaction forces	In agreement with the physicist	35	29	34
Named Force/cause	External to object	Interaction forces	Not in agreement with the physicist	0	3	1
Named Force/cause	External to object	Other causes	Pressure	0	0	0
Named Force/cause	External to object	Other causes	Others	0	0	0
Unclassified				2	3	1
Answers left out	Force acting on other object			4	0	0
Answers left out	Force/Cause finished			0	0	0

GROUP: G

SITUATION: 1

Kind of Answers						
Non-named Force/Cause	Nil	N		6	3	3
		Name says nothing		1	0	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	1	0
		Function of state	Motion/Speed ...	0	12	0
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	28	19	13
			Not in agreement with the physicist	4	7	3
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				6	0	0
Answers left out	Force acting on other object			4	0	0
	Force/Cause finished			0	0	0

GROUP: G

SITUATION: 2

Kind of Answers						
Non-named Force/Cause	Nil	N		4	5	3
		Name says nothing		1	0	3
	Replication of the event			0	0	1
Named Force/cause	Internal to objects	Force/Cause referred to past condition		0	0	0
		Function of state	Motion/Speed ...	9	9	10
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	16	18	16
			Not in agreement with the physicist	12	6	8
		Other causes	Pressure	0	0	0
			Others	0	0	0
Unclassified				4	0	3
Answers left out	Force acting on other object			0	0	0
	Force/Cause finished			0	0	0

GROUP: G

SITUATION: 3

Kind of Answers						
Non-named Force/Cause	Nil	N		2	2	5
		Name says nothing		1	1	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		3	3	0
		Function of state	Motion/Speed ...	10	8	4
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	24	22	14
			Not in agreement with the physicist	5	3	8
		Other causes	Pressure	0	0	2
			Others	0	0	0
Unclassified				2	3	0
Answers left out	Force acting on other object			2	0	0
	Force/Cause finished			0	0	0

GROUP: G

SITUATION: 4

Kind of Answers						
Non-named Force/Cause	Nil	N		5	4	2
		Name says nothing		0	0	0
	Replication of the event			0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition		1	1	0
		Function of state	Motion/Speed ...	0	9	0
			Energy	0	0	0
		Property of the object		0	0	0
	External to object	Interaction forces	In agreement with the physicist	15	16	14
			Not in agreement with the physicist	3	6	6
		Other causes	Pressure	0	1	0
			Others	0	0	0
Unclassified				1	3	2
Answers left out	Force acting on other object			1	0	0
	Force/Cause finished			0	0	0

GROUP: G

SITUATION: 5

Kind of Answers							
Non-named Force/Cause	Nil	N			4	3	3
		Name says nothing			0	1	1
	Replication of the event				0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			5	1	1
		Function of state	Motion/Speed ...		9	7	9
			Energy		0	0	0
		Property of the object			0	0	0
	External to object	Interaction forces	In agreement with the physicist		15	15	18
			Not in agreement with the physicist		6	4	4
		Other causes	Pressure		2	2	2
			Others		0	0	0
Unclassified					1	1	1
Answers left out	Force acting on other object				1	0	0
	Force/Cause finished				0	0	0

GROUP: G

SITUATION: 6

Kind of Answers							
Non-named Force/Cause	Nil	N			4	3	4
		Name says nothing			0	1	1
	Replication of the event				0	0	0
Named Force/cause	Internal to objects	Force/Cause referred to past condition			0	1	0
		Function of state	Motion/Speed ...		0	10	4
			Energy		0	0	0
		Property of the object			0	0	0
	External to object	Interaction forces	In agreement with the physicist		21	20	20
			Not in agreement with the physicist		5	3	7
		Other causes	Pressure		0	2	0
			Others		0	0	0
Unclassified					3	1	3
Answers left out	Force acting on other object				2	0	1
	Force/Cause finished				0	0	0

ANALYSIS OF THE PROBLEMATIC RESULTS

(i) Unclassified cases and answers left out

(i.1) Unclassified cases

Percentage of Unclassified Answers	Percentage of Situations						
	Group A	Group B	Group E	Group C	Group G	Group D	Group F
0% (or nearly 0%)	85%	95%	0%	70%	45%	70%	55%
5%	10%	5%	85%	30%	45%	25%	30%
10%	5%	-	15%	-	15%	5%	15%
>10%	-	-	-	-	-	-	-

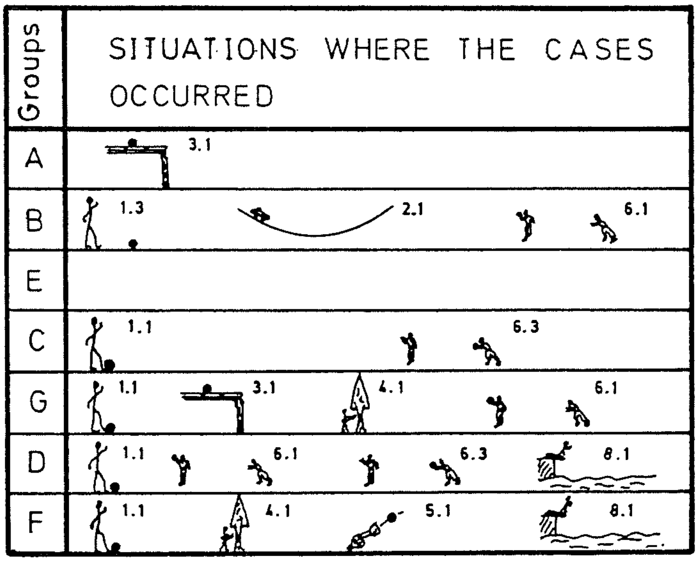
TABLE AIII - 1: Percentage of students' answers included in the Unclassified category in all situations and for each group

Table AIII - 1, showing the percentage of students' answers included in the Unclassified category in all situations and for each group, indicates that the percentage of such answers is rather small for any group in almost all situations. For no group, is the percentage of unclassified answers higher than 10% and, for the majority of the situations, this percentage is nearly zero. It was students who had ceased their studies in physics for some years (groups E and G) who, a little more frequently, gave such answers. Thus, in general, the names given to forces appear to contain useful information about the forces chosen, in the light of the network developed.

(i.2.1) Forces acting on other objects

Percentage of Forces Acting on Other Objects	Percentage of Situations						
	Group A	Group B	Group E	Group C	Group G	Group D	Group F
0% (or nearly 0%)	95%	85%	100%	90%	80%	80%	80%
5%	5%	15%	-	10%	15%	15%	5%
10%	-	-	-	-	5%	5%	15%
>10%	-	-	-	-	-	-	-

(a)



(b)

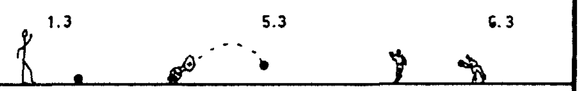
TABLE AIII - 2: (a) Percentage of students' choices of Forces Acting on Other Objects, in all situations and for each group and (b) situations where those choices occurred

Table AIII - 2(a), shows the percentage of choices of forces acting on objects other than the one specified in the questionnaire. It indicates, in line with the discussion in Chapter 5, sub-section 5.1.1, that for all groups and in the majority of situations the number of such answers is rather small (never higher than 10%). Students with more experience in physics (groups D and F) were those who considered such forces a little frequently than most. Table AIII - 2(b) shows that the situations where there is an action by contact, e.g. sit. 1-1, a man kicking a ball, sit. 6-1 and 6-3, a man throwing and catching a ball, are those where those cases more often occurred.

(i.2.2) Force/Cause finished

Percentage of Forces/ Causes Finished	Percentage of Situations						
	Group A	Group B	Group E	Group C	Group G	Group D	Group F
0% (or nearly 0%)	85%	100%	95%	100%	100%	100%	100%
5% - 10%	10%	-	5%	-	-	-	-
>10% ∧ ⩽ 20%	5%	-	-	-	-	-	-
> 20%	-	-	-	-	-	-	-

(a)

Groups	SITUATIONS WHERE THE CASES OCCURRED
A	
E	

(b)

TABLE AIII - 3: (a) Percentage of students naming a Force/Cause finished, in all situations and for each group and (b) situations where those choices occurred

Table AIII - 3(a), showing the percentage of choices where the names suggest that the force/cause is no longer acting, indicates again in agreement with the discussion in Chapter 5, sub-section 5.1.1., that such answers are also rare. Actually, they were only given by the youngest pupils (group A) and by Arts university students (group E) and the percentage of such answers is never higher than 20%. Table AIII - 3(b) suggests that situations where the motion had ceased, e.g. a ball at rest after being kicked by a man (sit. 1-3), are the ones which had prompted these answers.

Although the frequency of the answers described above were not large, they suggest ways to improve the questionnaire for any future use. It would be useful with respect to forces acting on other objects, to mention more clearly, in the questionnaire, the object on which the forces are supposed to act.

APPENDIX IV

ANALYSIS OF THE RESULTS FOUND IN SIT. 6-3 AND 8-1 CONCERNING CHOICES OF AN IMPULSIVE FORCE

This Appendix presents the analysis of the results found, by considering names given to the 'impulsive force' for sit. 6-3 (catching a ball) and sit. 8-1 (jumping from a springboard). Difficulties in interpreting the data, with respect to choices of directions of such a force, were found in the analysis done in Chapter 6, sub-section 6.2.1.5.

Given the kind of data found for these two situations (e.g. generally, the small number of choices of a force along the direction of the impulsive force) and the problematic aspects of the results, an analysis of individual answers, for each group and in each of the situations, was carried out, taking into account the suggestions made in Chapter 6, sub-section 6.2.1.5. The aim of the analysis was to see, whether the reduced number of choices of an impulsive force was mainly due to misinterpretations of the events or, whether these situations really attracted fewer such choices, which could mean that such a force is dependent on the context. However, as it will be shown next, this analysis did not help much the clarification of these questions because an appreciable number of students' answers present difficulties of interpretation.

<u>Sit. 6-3: a man catching a ball</u>

The analysis of individual answers given to sit. 6-3 suggested the following categories of replies:

(i) **a force/cause is needed to stop the motion/instant of the action,** which includes choices of an impulsive force in agreement with the physicist. It also includes answers suggesting the choice of an impulsive force but acting in other directions than the one expected, mainly, horizontally to the left. This category is the one which corresponds to the expected interpretation of the event;

(ii) **a force/cause is needed but to mantain the motion/ball still in motion (no action yet),** which includes answers suggesting that students misinterpreted the event in that they considered the ball still in motion. Typical answers were those named 'force of the speed', 'force of the motion';

(iii) **no force/cause exists either related to the action or to the motion/ball already stopped (after the action),** which includes answers suggesting that students misinterpreted the event in that they considered the ball already at rest. Typical answers were those in which no force was chosen at all or answers in which only gravity or gravity and Reaction were chosen. Furhter evidence to this interpretation comes also from some students' choices in which they wrote: 'there is no longer a force because the man already caught the ball';

(iv) **unclassified,** which includes answers which had no clear interpretation. They correspond to either named forces included in the **unclassified** category (see network defined in Chapter 7, sub-section 7.2.3) or and mainly, to non-named forces chosen in such directions that the answers given by these students, in the other instants, did not help to infer what these forces could be.

Table AIV -1 shows, for each group, the percentage of students included in each of the categories defined above.

Category of Replies	Percentage of Students						
	GP A	GP B	GP E	GP C	GP G	GP D	GP F
(i) (...) Instant of the action	15%	5%	10%	10%	40%	45%	45%
(ii) (...) Ball still in motion	27.5%	15%	10%	10%	20%	10%	5%
(iii) (...) Ball already stopped	30%	20%	25%	30%	5%	20%	25%
(iv) Unclassified	27.5%	60%	55%	50%	35%	25%	25%

TABLE AIV - I: Percentage of students, of each group, included in the categories of replies defined for sit. 6-3

In general, and despite the noticeable variations with groups in the percentage of students included in each category defined, the results suggest that:

(a) a considerable proportion of all students misinterpreted the situation (usually, more than 30%);

(b) the percentage of **unclassified** replies is rather high, mainly for groups with little or some experience in dynamics, a result wich is difficult to interpret.

From the above, it seems safest to regard sit. 6-3 as ambiguous with regard to impulsive forces.

Sit. 8-1: a man jumping from the springboard of a swimming pool

The analysis of individual answers given to sit. 8-1 suggested the follwoing categories of replies:

(i) **a force/cause is needed for the action of the board,** which includes choices of a force suggesting that students were thinking of the action of the springboard on the man (e.g. named forces such as 'force given by the springboard'). Students giving such answers are taken as having described an impulsive force and as having interpreted the situation as expected;

(ii) **a force/cause is needed but related with the man's effort/action,** which includes answers in which a 'force' was chosen but the name/direction given suggested that the force was related with the man, either with the man's effort or with the man's action of jumping or falling down. Typical answers were named forces such as 'the force of the man', referring to the man's effort; and 'weight', 'force of the falling', referring to the man's action of jumping or falling down. These answers suggested that students' attention was not on the action of the springboard but on the man. It may be that these replies ignore the impulsive force, or perhaps that the situation, in which a less massive and less 'powerful' agent (the springboard) is acting on a more massive and more 'powerful' agent (the man), contributed to such kind of responses;

(iii) **no force/cause is needed for the action of the board/man,** which includes answers in which no force related with the action of the springboard/man was chosen. Typical replies are those in which no forces were chosen at all or answers in which only gravity or gravity and Reaction were chosen. These answers suggest that students misinterpreted the event, in that they considered it occurring before the instant of jumping;

(iv) **unclassified,** including answers which were not interpretable. They correspond to either named forces which were included, according to the network defined in Chapter 7 sub-section 7.2.3, in the **unclassified** category or non-named choices. With respect to these I have decided that insufficient evidence was contained in the data, for making inferences about the meaning of these choices.

Table AIV - 2 shows, for each group, the percentage of students included in each of the categories defined above (group G was not asked about this situation).

Category of Replies	Percentage of Students					
	GP A	GP B	GP E	GP C	GP D	GP F
(i) (...) Action of the board	7.5%	5%	2.5%	10%	15%	40%
(ii) (...) Man's effort/ /action	37.5%	27.5%	15%	15%	12.5%	-
(iii) (...) No action of the board/man	10%	7.5%	10%	15%	27.5%	35%
(iv) Unclassified	45%	60%	72.5%	60%	45%	25%

TABLE AIV - 2: Percentage of students, of each group, included in the categories of replies defined for sit. 8-1

The most noticeable feature of the results is the large percentage of Unclassified answers which makes it rather difficult to interpret the results. Even so, they seem to suggest that:

(a) only a minority of students of all groups considered an impulsive force in sit. 8-1, except group F, where 40% of students did so;

(b) an appreciable percentage of the youngest groups (A and B) considered, instead, a force/cause related with the man's effort/action, this percentage seeming to decrease with teaching, at least, for Physics trainee teachers.

In conclusion, but not forgetting the difficulties found in the analysis of the results found in the two situations studied above, one may say that the event of sit. 6-3 seemed to have presented ambiguities of interpretation, while sit. 8-1 seemed to be a case where impulsive forces are less often chosen, at least by the the youngest students.